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Policy Transmission in DSGE and VAR models

Gernot J. Müller

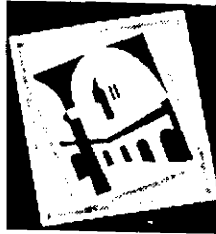
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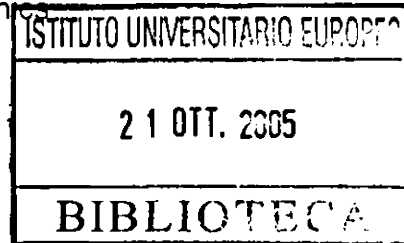




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Department of Economics

Ph.D. dissertation

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Introduction

This thesis consists of three papers, analysing the effects of government spending on foreign trade, the role of financial frictions in the transmission of monetary policy and changes over time in the effects of fiscal policy, respectively. To address these issues I combine Vector Autoregressions (VAR) and Dynamic Stochastic General Equilibrium (DSGE) models of the New Keynesian type.

In each chapter the focus is on policy innovations or shocks, i.e. exogenous differences between private sector expectations and realizations of policy variables. The transmission of these shocks, i.e. the induced adjustment process of the economy, is investigated, because it is informative about the channels through which monetary and fiscal policies affect the economy. It is neatly summarized by impulse response functions both in the DSGE and the VAR model and therefore it seems natural to consider this statistic as the critical nexus between theory and data.

The first chapter is entitled "Understanding the Dynamic Effects of Government Spending on Foreign Trade." It is motivated by a recent VAR analysis of Kim and Roubini (2003) whereby an exogenous increase in the budget deficit is found to reduce the current account deficit. Since this is in stark contrast with the popular twin deficit hypothesis, it is worthwhile to explore the ability of a New Keynesian DSGE model to account for this finding.

To do so, I focus on only government spending shocks both in a VAR on U.S. time series and the DSGE model. This allows a clear mapping of the model impulse response functions into those of the VAR. The latter show a depreciation of the nominal exchange rate, an appreciation of the terms of trade and an increase in net exports in response to an exogenous increase in government spending. If the model is exposed to the same shock, it is shown to match qualitatively the response of relative prices. The response of net exports, in contrast, depends on the intra- and intertemporal elasticities of substitution and the degree of home bias in private consumption. Since the empirical findings are new and not yet well established in the literature it seems important to establish that, in principle, the New Keynesian DSGE model is able to account for the sign of the impulse response functions. However, the impulse response functions are matched only qualitatively, as the DSGE model is not rich enough to capture fully the dynamics observed in the data.

The second chapter, co-authored with André Meier, is entitled "Fleshing out the Monetary Transmission Mechanism: Output Composition and the Role of Financial Frictions." Given that financial frictions affect the way in which different components of GDP respond to a monetary policy shock, we aim to establish whether such frictions can play a quantitatively important role in accounting for monetary policy transmission. In the words of Woodford (2003) one needs to "flesh out the details of a quantitatively realistic account of the monetary transmission mechanism."

We therefore embed the financial accelerator of Bernanke, Gertler and Gilchrist (1999) into a medium scale New Keynesian DSGE model and evaluate the relative importance of financial frictions in accounting for the transmission of monetary policy. Specifically, we match the impulse responses generated by the model with empirical impulse response functions obtained from a VAR on US time series data. This allows us to provide estimates for the structural parameters of our model and to judge the relevance of different model features. In addition, we propose a set of simple and instructive specification tests that can be used to assess the relative fit of various restricted models. Although we find mild evidence for financial frictions, they are of minor importance for the descriptive quality of the model.

The third chapter, co-authored with Florin Bilbiie and André Meier, is entitled "Asset Market Participation, Monetary Policy and the Effects of US Government Spending: What Accounts for the Declining Fiscal Multiplier?" This research starts from the observation of Perotti (2005) that the effects of fiscal policy are considerably weaker in the post-1980s if compared with earlier periods.

Using a VAR on U.S. time series and comparing the periods 1957-1979 and 1983-2004, we provide further evidence that the responses of output, wages and consumption to a government spending shock are typically weaker in the second sample. In a second step, this observation is rationalized within a New Keynesian DSGE model featuring non-asset holding agents. Specifically, the structural parameters of the model are estimated for both samples by matching impulse response functions. We find that asset market participation increased from about fifty to about seventy percent. In order to assess whether this increase accounts for the declining fiscal multiplier we run counterfactual model-based experiments. These experiments point to an important role of asset market participation in fiscal transmission, but also show that changes in the conduct of monetary policy may be key in accounting for the declining fiscal multiplier.

Finally, I am very much indebted to Giancarlo Corsetti and Roberto Perotti for their advice and guidance while writing this thesis.

Chapter 1

Understanding the Dynamic Effects of Government Spending on Foreign Trade

1.1 Introduction

The present paper studies the dynamic effects of a temporary increase in government spending on foreign trade. Its aim is twofold. First, it seeks to establish empirically how the exchange rate, the terms of trade and the trade balance (net exports) respond to an exogenous increase in government spending. Second, it rationalizes these responses within a stochastic general equilibrium model which features price rigidities and thus gives an important role to monetary policy.

Empirical investigations, based on Vector Autoregressions (VAR), of the dynamic effects of fiscal policy within a closed economy context have become more numerous recently. Attempts have also been made to account for this evidence using different versions of stochastic general equilibrium models, e.g. Fatás and Mihov (2001), Burnside, Eichenbaum and Fisher (2004) and Gali, López-Salido and Vallés (2004). Little evidence, however, has been put forward regarding the dynamic effects of government spending on foreign trade. Exceptions are Kim and Roubini (2003) and Giuliadori and Beetsma (2004), who do not, however, explore their empirical findings within a formal theoretical framework. Canzoneri, Cumby and Diba (2003) also provide a VAR analysis of the effects of fiscal policy on foreign trade and, although they analyze their findings within a general equilibrium model, they make the restrictive assumption that trade is always balanced.

From a policy perspective, the recent U.S. macroeconomic stance provides a particular motivation to investigate the dynamic effect of fiscal policy on foreign trade in a loose monetary environment. It is often assumed that the current fiscal stance is contributing to the ongoing deterioration of the U.S. trade balance, thus stimulating the global economy at the expense of increased global imbalances, see, e.g. International Monetary Fund (2004). At the same time the current accommodating

monetary policy stance is generally thought to have an opposite effect on net exports.¹ Hence, the overall effect of the expansionary U.S. fiscal-monetary stance on the U.S. trade balance appears to be unclear.

Against this background, this paper takes up these issues both at an empirical and a theoretical level. The main results of the empirical analysis can be summarized as follows. It finds that following a temporary increase in government spending the nominal exchange rate depreciates, the terms of trade appreciate and net exports increase. These results are obtained from a VAR on U.S. time series data for the post-Bretton-Woods period. While somewhat surprising, the result regarding the trade balance is consistent with previous findings of Kim and Roubini regarding the current account.

The theoretical analysis is based on a model that belongs to a recent class of stochastic general equilibrium models for open economies which also feature sticky prices, see, for example, Benigno and Benigno (2003), Chari, Kehoe and McGrattan (2002) and Galí and Monacelli (2004). The model is formulated in discrete time and linearized around a non-stochastic steady state. In such a framework an exogenous increase in government spending generates dynamic effects comparable to those identified in the data by means of a VAR. Price stickiness, in turn, gives a non-trivial role to monetary policy in determining the equilibrium response to a temporary increase in government spending. This is investigated by assuming that monetary policy is endogenously characterized by an interest rate feedback rule.

The main results of the theoretical analysis are as follows. First, because of home bias in government spending, the terms of trade appreciate after an exogenous increase in government spending. Next, under the assumption that international financial markets are complete, the relative size of the elasticities of intertemporal and intratemporal substitution, together with the degree of home bias in private consumption, are key for the sign of the response of the trade balance. If the elasticity of intertemporal substitution exceeds the elasticity of intratemporal substitution, net exports will increase after an increase in government spending if private consumption is substantially home biased.²

Second, regarding the role of monetary policy, the sign of the response of the

¹In the standard one-good intertemporal model of the current account, a temporary increase in government spending lowers net exports, see Ahmed (1986) for a seminal study and Kollmann (1998) for an exploration within a two-country RBC model. Also, in the Mundell-Fleming model with flexible exchange rates and perfect capital mobility a fiscal expansion in the home country increases domestic demand for both home and foreign goods thereby reducing net exports, see the discussion in Svensson (1987). In contrast, an expansionary monetary policy is thought to depreciate the exchange rate and to switch expenditure towards home goods.

²The role of these elasticities for the international transmission of policy shocks has also been highlighted by Svensson (1987), Van der Ploeg (1993), Corsetti and Pesenti (2001) and Tille (2001). However, for different reasons these models are less suitable for a comparison with the VAR evidence obtained in the first part of the present paper. One common feature in Svensson, Corsetti and Pesenti and Tille is that prices or wages are assumed to be set one period in advance. This implies that these models distinguish between the short run and long run effects of a policy shock. Van der Ploeg introduces nominal rigidities by means of an augmented Phillips Curve, but sets up his model in continuous time.

terms of trade and the trade balance is shown to be independent of the monetary regime. However, an accommodating monetary policy in the home country dampens the effect of the fiscal shock both on the terms of trade and the trade balance. Finally, it is also shown that assuming incomplete international financial markets does not affect the results qualitatively.

The remainder of the paper is organized as follows. In the next section, evidence on the dynamic effects of government spending is obtained by means of a VAR on U.S. time series data. Section 3 describes the theoretical model, while Section 4 provides some analytical insights into the transmission of fiscal shocks as well as a numerical solution of the model. Section 5 concludes.

1.2 The Evidence

So far, only a few empirical studies have investigated the dynamic effects of fiscal policies on foreign trade. There is some VAR-based evidence, however, that fiscal expansions affect exchange rates and foreign trade. Clarida and Prendergast (1999) consider an increase in the structural deficit in Germany, Japan and the U.S. and find that the real exchange rate appreciates on impact, while this effect is reversed later. Canzoneri, Cumby and Diba (2003) also find a real appreciation of the dollar after an increase in U.S. government spending. In addition, they observe a positive effect on foreign GDP (France, Italy and the U.K.). Similar in spirit, Giuliodori and Beetsma (2004), using European data find an increase in imports after an increase in government spending, while they do not observe a major effect on the real exchange rate. In contrast to these studies, Kim and Roubini (2003), using U.S. data, find the real exchange rate to depreciate after a fiscal expansion and the current account to increase.

1.2.1 Baseline specification

These studies provide the starting point for the following analysis and motivate the choice of variables included in the VAR. Instead of the real exchange rate, I include both the nominal exchange rate and the terms of trade. The terms of trade are more likely to capture the cross-border substitution process induced by fiscal expansions as they provide a measure for the relative price of tradeables only. The nominal exchange rate is included to account for monetary phenomena during the transmission of fiscal shocks. Finally, I include the trade balance (net exports) as a summary statistic for the effects of fiscal policy on foreign trade.

Specifically, I include six variables in the baseline VAR: the log of real government spending per capita, the log of real GDP per capita, the log of the GDP deflator, the log of the nominal exchange rate, the log of the terms of trade and the trade balance.³ The baseline specification includes four lags of each endogenous variable.

³Net taxes, the real exchange rate and interest rates are also considered below. Most of the data are from the NIPA available online at the Bureau of Economic Analysis. Real government spending

a constant and a linear time trend. For the estimation U.S. quarterly data from the post-Bretton-Woods period (1973:1 - 2003:4) are used.

In order to identify an exogenous shock to government spending, it is assumed that government spending does not respond contemporaneously to changes in the other variables included in the VAR. This assumption goes back to Blanchard and Perotti (2002) and Fatás and Mihov (2001) and is now widely used in the VAR literature on fiscal policy. It appears justified, because government spending is defined as government consumption and investment and does not include transfer payments.⁴

Figure 1 displays the responses to a fiscal shock, i.e. a one percent increase in government spending. While the solid line gives the point estimates, the shaded area gives the 95 percent confidence interval, computed by the Hall bootstrap procedure based on 1000 replications. Government spending rises significantly and persistently, with a half-life of about six quarters. GDP rises significantly on impact and remains above trend for almost two years. Given an average share of government spending in GDP of twenty percent, I find a government spending multiplier on output of about one, i.e. a value similar to the one reported by Blanchard and Perotti (2002). Prices fall after an increase in government spending (though not significantly), a finding also reported in other studies, e.g. Mountford and Uhlig (2001) and Perotti (2005).⁵

Now consider the dynamic effects of a temporary increase in government spending on variables which characterize external trade. The nominal exchange rate depreciates on impact and this effect becomes stronger and significant after six quarters. The terms of trade, on the other hand, appreciate sharply on impact, with the peak response in the third quarter and are back at the pre-shock level after six quarters. Finally, net exports increase on impact, significantly so in the second quarter after the shock and remain above trend for an extended period. This finding is in line

is the sum of government consumption expenditures (A955RC1) and gross government investment (A782RC1) deflated with the deflator of government consumption and investment (A822RD3). Real net taxes are taxes (W021RC1) less transfers (A084RC1) and subsidies (A107RC1) deflated with the GDP deflator (A191RD3). Real GDP is nominal GDP (A191RC1) deflated with the GDP deflator (A191RD3). The terms of trade are constructed as the price index of imports (A021RD3) over the price index of exports (A020RD3). The trade balance is constructed as the ratio of exports (B020RC1) less imports (B021RC1) over GDP (A191RC1). The nominal and real effective exchange rates, which are taken from the IFS, are inverted such that an increase corresponds to a depreciation. The 10 year nominal interest rate is obtained from the FRED database of the St. Louis Fed. Quarterly population figures are also provided by the NIPA tables (B230RC0).

⁴The analysis of Canzoneri et al. (2003) is also based on this identifying assumption. The baseline specification of Kim and Roubini (2003), in contrast, is based on the assumption that GDP does not contemporaneously respond to changes in the fiscal balance. However, Kim and Roubini perform various robustness tests, including the identification scheme used in the present paper. They find that the results are essentially unaltered. I also consider an alternative identification scheme below.

⁵Perotti (2005) shows that it may result from assuming a zero price elasticity of real government spending (in the present identification scheme) and that the effect becomes weaker if a non-zero elasticity is assumed. Linnemann and Schabert (2003) show in a closed economy model that the effect of government spending on the price level ultimately depends on the relative importance of the supply (i.e. wealth) effect and the demand effect (i.e. the degree of price rigidity).

with the results of Kim and Roubini regarding the current account.⁶

1.2.2 Robustness

In order to explore the robustness of the results, different specifications of the trend, the inclusion of additional/alternative variables and an alternative identification scheme are considered. In the light of difficulties to distinguish clearly between stochastic and deterministic trends on the basis of formal tests, Blanchard and Perotti (2002) base their analysis on both specifications. Also, in case of stochastic trends it is hard to establish clear evidence in favor of cointegration where suggested by economic theory (as in the case of taxes and government spending). Clearly, in the present case where interest is not centered on the cointegration relationship it might be sensible to resort to the level specification which can accommodate for stochastic trends as well. Against this background, this paper follows Perotti (2005) and considers the following alternatives to the baseline specification: i) quadratic trend; ii) levels; iii) stochastic trend;⁷ and iv) a stochastic trend with cointegration between spending and taxes (for that purpose taxes are included in the VAR). The left column of Figure 2 displays the results for the variables of interest, where the shaded area gives the 95 percent confidence interval of the baseline specification (linear trend). For all specifications the qualitative predictions of the model are unchanged, except for the response of the terms of trade under the imposed cointegration relationship between government spending and taxes.

Next, variables that have been left out under the presumption that they do not affect the response of the variables of interest to a temporary increase in government spending are included in the VAR. Additional variables are i) the 10-year nominal interest rate; and ii) net taxes. For the identification of the exogenous spending shock, both variables are also assumed not to affect government spending contemporaneously. Alternative variables are iii) public spending deflated with the GDP deflator (instead of being deflated with its own deflator) and iv) the real exchange rate (instead of the nominal exchange rate). A last aspect concerns the identification of an exogenous shock to government spending. So far, a shock to government spending has been identified by the assumption that government spending does not contemporaneously respond to any other variables included in the VAR. This assumption may be somewhat restrictive with respect to the price level. Perotti (2005) argues that depending on the degree of indexation of government spending, it might be reasonable to assume that real government spending falls if the price level increases. Only if government spending were fully (and without a lag) indexed to inflation, the zero restriction would be fully appealing. Therefore, this paper follows Perotti and considers the identification of an exogenous increase in government spending

⁶Baxter (1995) emphasizes that the trade balance and the current account display very similar short-run properties.

⁷First differences of the variables are used in the regression and the accumulated impulse responses are reported. No allowance, however, is made for changes in the underlying drift as in Blanchard and Perotti (2002).

based on the assumption that the price elasticity of real government spending is -0.5 (instead of zero in the baseline case). The right column of Figure 2 displays the results of all five experiments, which are well within the confidence bands of baseline specification.

Against this background, the dynamic effects of a temporary increase in U.S. government spending during the flexible exchange rate period 1973-2003 can be summarized as follows: the nominal exchange rate depreciates, the terms of trade appreciate and the trade balance improves.

1.3 The Model

To rationalize the evidence obtained from the VAR a two-country general equilibrium model is proposed.⁸ Given the significant response of relative prices to an exogenous increase in government spending, the response of the trade balance may reflect a reallocation of expenditure across home and foreign goods. The model therefore assumes that both countries supply distinct goods to the world market and gives a prominent role to the determinants of the intratemporal consumption allocation across these goods. Both countries are populated by a continuum of households which consume identical consumption goods within each country and provide differentiated output goods. In setting prices for these goods, households are exogenously constrained à la Calvo. Fiscal policy is characterized by an exogenous process for government spending financed entirely through lump-sum taxes. It is assumed that while private consumption is home biased, government spending falls entirely on domestic goods. To close the model, monetary policy is characterized by an interest rate feedback rule. Moreover, two cases are distinguished, a case where financial markets are complete at the international level and one where only riskless assets are traded across countries. To simplify the exposition, only the home economy is considered and the following notation is used: foreign variables within the home economy are indexed with the subscript "F", while foreign variables in foreign are indexed with a star.

1.3.1 Intratemporal expenditure allocation

A generic home household i , with $i \in [0, 1]$, consumes a composite good, C_t , and provides a differentiated good, $Y_{t+k}(i)$, to the world market. The objective of the household is to maximize

$$E_t \left\{ \sum_{k=0}^{\infty} \beta^k [u(C_{t+k}) - v(Y_{t+k}(i))] \right\}. \quad (1.1)$$

⁸The model belongs to a class of stochastic general equilibrium-models, which combine optimization behavior at the micro-level with price stickiness to address problems of the open economy, see, e.g. Benigno and Benigno (2003), Chari, Kehoe and McGratten (2002) and Galí and Monacelli (2004).

where $0 < \beta < 1$ is a discount factor. The period contribution of utility u is assumed to be concave and increasing. The period contribution of disutility v is assumed to be convex and increasing. E_t denotes expectations conditional on the information set at date t . The composite good C_t is an aggregate of home and foreign bundles of differentiated goods, $C_{H,t}$ and $C_{F,t}$, respectively, such that

$$C_t = \left[\theta^{\frac{1}{\varepsilon}} C_{H,t}^{\frac{\varepsilon-1}{\varepsilon}} + (1-\theta)^{\frac{1}{\varepsilon}} C_{F,t}^{\frac{\varepsilon-1}{\varepsilon}} \right]^{\frac{\varepsilon}{\varepsilon-1}},$$

where $\varepsilon > 0$ provides a measure for the intratemporal elasticity of substitution between the home and foreign goods and $1/2 \leq \theta \leq 1$ for the home bias in private consumption. Consequently, the domestic and foreign composite goods differ for all $\theta > 1/2$. Home and foreign goods are bundled according to the CES technology

$$C_{H,t} = \left(\int_0^1 C_{H,t}(j)^{\frac{\mu-1}{\mu}} dj \right)^{\frac{\mu}{\mu-1}}, \quad C_{F,t} = \left(\int_0^1 C_{F,t}(j)^{\frac{\mu-1}{\mu}} dj \right)^{\frac{\mu}{\mu-1}},$$

where $C_{H,t}(j)$ and $C_{F,t}(j)$ denote differentiated goods produced by household $j \in [0, 1]$ in home and foreign, respectively. $\mu > 1$ denotes the price elasticity of demand for differentiated output goods. $P_{H,t}(j)$ and $P_{F,t}(j)$ denote the price (denoted in home currency) of domestic good j and foreign good j , respectively. The price indices for home and foreign good bundles are defined as $P_{H,t} = \left(\int_0^1 P_{H,t}(j)^{1-\mu} dj \right)^{\frac{1}{1-\mu}}$ and $P_{F,t} = \left(\int_0^1 P_{F,t}(j)^{1-\mu} dj \right)^{\frac{1}{1-\mu}}$. The domestic consumer price index is given by

$$P_t = \left[\theta P_{H,t}^{1-\varepsilon} + (1-\theta) P_{F,t}^{1-\varepsilon} \right]^{1/(1-\varepsilon)}. \quad (1.2)$$

Let S_t denote the nominal exchange rate, i.e. the price of foreign currency in terms of domestic currency. While the law of one price holds, i.e.

$$S_t = P_{H,t}/P_{H,t}^*, \quad (1.3)$$

purchasing power parity does not hold for $\theta > 1/2$. For future reference it is also useful to define the terms of trade as the relative price of foreign goods to domestic goods

$$\tilde{\tau}_t = P_{F,t}/P_{H,t}. \quad (1.4)$$

Since government spending, G_t , is assumed to fall entirely on domestic goods, an optimal allocation of expenditure implies that the demand for a generic home good, $Y_t^D(j)$, is given by

$$Y_t^D(j) = \left(\frac{P_{H,t}(j)}{P_{H,t}} \right)^{-\mu} \left\{ \left(\frac{P_{H,t}}{P_t} \right)^{-\varepsilon} (\theta C_t + (1-\theta) C_t^*) + G_t \right\}. \quad (1.5)$$

For future reference let $Y_t = \left[\int_0^1 Y_t(j)^{\frac{\mu-1}{\mu}} dj \right]^{\frac{\mu}{\mu-1}}$ denote the bundle of differentiated goods produced in the home country, which corresponds to domestic output. Finally,

the trade balance, TB_t , expressed in domestic consumer prices is defined as exports less imports

$$TB_t = \frac{P_{H,t}}{P_t} \left(\frac{P_{H,t}^*}{P_t^*} \right)^{-\varepsilon} (1 - \theta) C_t^* - \frac{P_{F,t}}{P_t} \left(\frac{P_{F,t}}{P_t} \right)^{-\varepsilon} (1 - \theta) C_t. \quad (1.6)$$

1.3.2 Financial markets

Two different structures of financial markets are considered. In both cases financial markets are complete within countries. This assumption introduces homogeneity of households within a country with respect to consumption decisions as households can perfectly insure the risk resulting from the price setting decisions discussed below. However, in the first case, international financial markets are complete as well, while in the second case, only non-state-contingent assets are traded across countries.

In the first case, financial markets are complete, both at the domestic and the international level and the set of state-contingent assets is denoted in domestic currency. The absence of arbitrage opportunities requires that there exists a stochastic discount factor $Q_{t,t+1}$ which is used to price the portfolio A_{t+1} in period t .⁹ The budget constraint of a representative home household is then given by

$$P_t C_t + E_t \{Q_{t,t+1} A_{t+1}\} + T_t = A_t + P_{H,t} Y_t, \quad (1.7)$$

where T_t denotes lump sum taxes. The maximization of (1.1) subject to (1.7) gives

$$\beta \frac{u'(C_{t+1})}{u'(C_t)} \frac{P_t}{P_{t+1}} = Q_{t,t+1}, \quad (1.8)$$

which holds in each possible state. Defining the short-term nominal interest rate as $R_t^{-1} = E_t \{Q_{t,t+1}\}$ and taking expectations of (1.8) gives the Euler equation

$$\beta E_t \left\{ \frac{u'(C_{t+1})}{u'(C_t)} \frac{P_t}{P_{t+1}} \right\} = R_t^{-1}. \quad (1.9)$$

As analogous relationships hold for the foreign economy, one obtains the risk sharing condition

$$u'(C_t^*) = k \frac{S_t P_t^*}{P_t} u'(C_t), \quad (1.10)$$

where k is a constant, see Chari, Kehoe and McGrattan (2002). Intuitively, the assumption of complete international asset markets induces perfect risk-sharing such that the marginal utility of consumption, weighted by the real exchange rate,

⁹As discussed in Woodford (2003, Ch. 2), A_{t+1} denotes the state-contingent value of the household portfolio at the beginning of period $t+1$. Thus, at the time of the portfolio decision A_{t+1} is a random variable, but the household chooses its complete specification, i.e. the return in each state. As of date t , $Q_{t,t+1}$ remains also a random variable and depends of the realization of the state in $t+1$. To simplify the notation, the state dependence of these variables is omitted, as in Galí and Monacelli (2004). An explicit treatment of state-dependence is given by Chari, Kehoe and McGratten (2002).

$S_t P_t^*/P_t$, is equalized across countries. If home and foreign goods have equal weight in private consumption, purchasing power parity holds, the real exchange rate is constant and consumption is equal across countries. If $\theta > 1/2$, an increase in the price of domestic goods induces *ceteris paribus* an appreciation of the real exchange rate and requires that the domestic consumption level falls relative to foreign in order for (1.10) to hold.

In the second case, international financial markets are incomplete, such that only riskless one-period bonds are traded across countries. As in Benigno (2001), households can allocate their wealth between a bond denominated in domestic currency, $B_{H,t}$, and one denominated in foreign currency, $B_{F,t}$. In order to ensure stationarity, a home household faces portfolio costs which are proportional to the position in the bond denominated in foreign currency, $\psi S_t B_{F,t+1}^2/(2P_t)$, as discussed in Schmitt-Grohé and Uribe (2003). The budget constraint of a representative home household is given by

$$\frac{S_t B_{F,t+1}}{R_t^*} + \frac{B_{H,t+1}}{R_t} + \frac{\psi}{2} S_t B_{F,t+1}^2 + P_t C_t + T_t = B_{H,t} + S_t B_{F,t} + P_{H,t} Y_t. \quad (1.11)$$

Maximization of (1.1) with respect to (1.11) also implies the Euler equation (1.9), but instead of the complete risk-sharing condition (1.10), the solution to the household problem with respect to foreign bond holdings now requires that

$$\frac{1 + \psi B_{F,t+1}}{R_t^*} = \beta E_t \left\{ \frac{U'(C_{t+1})}{U'(C_t)} \frac{P_t}{P_{t+1}} \frac{S_{t+1}}{S_t} \right\}. \quad (1.12)$$

In the following, it is assumed that bonds denominated in domestic currency are in zero net supply within the home country.

1.3.3 Price setting

Given monopolistic competition in the goods market and the resulting downward sloping demand functions, the price setting mechanism plays a crucial role for the real allocation of goods. It is assumed that price setting is constraint exogenously by a discrete time version of the mechanism suggested by Calvo (1983). In each period a generic household j has the opportunity to change its price with a given probability $1 - \alpha$, independently of previous price adjustments. If allowed to set a new price $P_{H,t}(j)$ in period t the household takes $P_t, P_{F,t}, P_{H,t}$ as given and seeks to maximize

$$E_t \sum_{k=0}^{\infty} \alpha^k \Lambda_{t,t+k} \left\{ \frac{u'(C_{t+k})}{P_{t+k}} P_{H,t}(j) Y_{t+k}^D(j) - v(Y_{t+k}^D(j)) \right\}.$$

subject to the demand function (1.5). $\Lambda_{t,t+k}$ denotes the intertemporal marginal rate of substitution. Note that revenues $P_{H,t}(j) Y_{t+k}^D(j)$ are evaluated using the marginal utility of income $u'(C_{t+k})/P_{t+k}$, which is identical to all households as a

result of complete income insurance within the country. The first order condition to this problem is given by

$$E_t \sum_{k=0}^{\infty} \alpha^k \Lambda_{t,t+k} Y_{t+k}^D(j) \left\{ \frac{P_{H,t}(j) u'(C_{t+k})}{P_{t+k}} - \frac{\mu}{(\mu-1)} v'(Y_{t+k}^D(j)) \right\} = 0. \quad (1.13)$$

Note that if prices are fully flexible, i.e. $\alpha = 0$, condition (2.5) implies that the price

$P_{H,t}(j)$ is set such that

$$P_{H,t}(j) / P_t = (\mu / (\mu - 1)) v'(Y_t^D(j)) / u'(C_t).$$

1.3.4 Policy

The government budget is balanced in each period, i.e. $T_t = P_{H,t} G_t$, and government spending follows an exogenous AR(1) process

$$G_t / G = (G_{t-1} / G)^\rho \exp u_t, \quad (1.14)$$

where letters without time-subscript refer to steady state values. For future reference, let $g = G/Y$ denote the steady state share of government spending. Monetary policy is characterized by an interest feedback rule such that the nominal interest rate is adjusted in response to inflation and the output gap,

$$R_t / R = (P_t / P_{t-1})^{\phi_\pi} \left(Y_t / Y_t^f \right)^{\phi_y}, \quad (1.15)$$

where Y_t^f denotes output that would prevail if prices were fully flexible.

1.3.5 Equilibrium

Given an initial allocation of $B_{F,0}$, an exogenous process for government spending G_t and the flex-price output Y_t^f , an equilibrium for the economy is defined by a sequence for domestic producer price inflation, $P_{H,t} / P_{H,t-1}$, foreign producer price inflation, $P_{F,t} / P_{F,t-1}$, consumer price inflation, P_t / P_{t-1} , the nominal interest rate, R_t , consumption, C_t , actual output, Y_t , as well as their foreign counterparts. In addition, a path for the nominal exchange rate, S_t , the terms of trade, τ_t , the trade balance, TB_t and the stock of debt, $B_{F,t}$ defines the equilibrium.

These sequences have to satisfy the following conditions both in home and foreign: the Euler equation (1.9) and the appropriate non-Ponzi games and transversality conditions, the first order condition for price setting (1.13), the definition of consumer price inflation implied by (1.2), the law of one price (1.3) and the good-market clearing conditions and the interest rate feedback rule (1.15). In addition, the definition of the trade balance (1.6) and the terms of trade (1.4) are used to characterize the equilibrium. Finally, under complete financial markets the riskless asset is redundant and the risk sharing condition (1.10) is required to hold, whereas

under incomplete financial markets the domestic budget constraint (1.11) and condition (1.12) determine the equilibrium allocation. The model will be analyzed in a form log-linearized around a deterministic steady state characterized by balanced trade and a zero net foreign asset position, see the appendix for details.

1.4 Government spending and foreign trade

Turning to the solution of the linearized model, note first that, unless defined otherwise, small letters are used to denote log-deviations from steady state. In order to investigate the transmission channels of fiscal shocks as well as the role of monetary policy for the equilibrium outcome analytical expressions will be derived under simplifying assumptions in the next subsection. These will be relaxed afterwards when the model is solved numerically.

1.4.1 Some analytical insights

A natural benchmark for the equilibrium outcome is given by the allocation that would prevail under flexible prices. Benigno and Benigno (2003) show that such an allocation is the equilibrium outcome in a two country model if monetary policy, both in home and foreign, maintains producer price stability. In the following, this allocation is referred to by means of a superscript "f". In this case households will have no incentive to adjust their prices in response to shocks occurring at the country level. The adjustment to shocks is achieved entirely through an adjustment of the nominal exchange rate.¹⁰ The following statement summarizes this result. The derivation is given in the appendix together with the other results that follow.

Result 1 (Flexible price allocation) *If international financial markets are complete and monetary policy maintains producer price stability in both countries, an exogenous increase in domestic government spending induces a fall in the terms of trade and the nominal exchange rate by the same amount $\tau_t^f = s_t^f = -(g/\xi) g_t$.*

Note that ξ is a positive constant which increases in the intertemporal elasticity of the supply of differentiated output, ω , as well as in the intra- and intertemporal elasticity of substitution, σ and ε , respectively, see expression (1.31) in the appendix. A fall in the terms of trade reflects an increase in the price of domestic goods relative to foreign goods. Intuitively, this is the consequence of the home bias in government spending. Note that this home bias need not be complete as in the present model, see, e.g. Backus, Kehoe and Kydland (1994). Moreover, if the provision of output is costly (low ω) and the elasticities of substitution are low (low σ and ε), a larger response of the terms of trade (low ξ) is required in order to induce a reallocation of resources in response to an exogenous increase in government spending.

Result 1 characterizes the flex-price allocation and provides a benchmark for an evaluation of the response of the terms of trade in case monetary policy does not

¹⁰Note that this mechanism constitutes the case for flexible exchange rates in Friedman (1953).

maintain producer price stability, but instead is characterized by an interest rate feedback rule. For the moment it is convenient to assume that the interest rates are not adjusted in response to the output gap, i.e. that $\phi_y = 0$ in equation (3.13). Moreover, it is assumed that monetary policy adjusts the nominal interest rate in response to producer price inflation instead of consumer price inflation. Let ϕ_π denotes the elasticity of the interest rate with respect to producer price inflation and κ the slope of the New Keynesian Phillips curve derived from the linearized price setting problem (1.13). Then one obtains the following result.

Result 2 (Sticky price allocation) *If international financial markets are complete and monetary policy adjusts the interest rate in response to producer price inflation, both in home and in foreign, the equilibrium is determinate if $\phi_\pi > 1$. If, in addition, government spending shocks display no persistence ($\rho = 0$), an exogenous increase in domestic government spending induces a fall in the terms of trade that is smaller than in the flex price case (and identical for $\phi_\pi \rightarrow \infty$): $\tau_t = -[g/(\xi + \omega/(\kappa\phi_\pi))]g_t$. The nominal exchange rate displays a unit root: it depreciates in the long run, but undershoots on impact (see appendix).*

Intuitively, monetary policy by adjusting interest rates in response to producer price inflation, is somewhat accommodating in the home country relative to the benchmark case where producer price stability is maintained. This is reflected in the path of the nominal exchange rate. A measure for the monetary stance during the transmission of fiscal shocks is provided by the natural interest rate, i.e. the real interest rate that is consistent with the flex price allocation, see Woodford (2003, p. 248). Therefore it is instructive to solve for the difference in the real interest rate between home and foreign and compare this *actual* interest rate differential with the *natural* interest rate differential. It is shown in the appendix that the actual interest rate differential, $(2\theta - 1)[g/(\xi + \omega/(\kappa\phi_\pi))]g_t$, is smaller than the natural interest rate differential, $(2\theta - 1)(g/\xi)g_t$, except for $\phi_\pi \rightarrow \infty$. Home monetary policy is thus accommodating for the fiscal shock as it prevents the real rate differential from increasing to the same extent as in the flexible price allocation. Note also that in the absence of home bias, $\theta = 1/2$, the interest rate differential is zero, as in this case consumption patterns are identical in both countries.

While an increase in domestic government spending unambiguously increases the prices of home goods relative to foreign goods, the response of the trade balance eventually depends on the relative size of the inter- and intratemporal elasticity of substitution, σ and ε , respectively, and the degree of home bias in private consumption, θ . This is established in the following result.

Result 3 (Trade balance) *If international financial markets are complete and government spending shocks display no persistence ($\rho = 0$), the response of the trade balance to an exogenous increase in domestic government spending is positive if $1 + (2\theta - 1)\sigma > 2\theta\varepsilon$. This is true for both the flexible and the sticky price allocation.*

Regarding the later case, the weaker the response of monetary policy to producer price inflation, the weaker the response of the trade balance. The response is strongest in case of producer price stability (flexible price allocation).

To understand the condition for an increase in the trade balance, $1 + (2\theta - 1)\sigma > 20\varepsilon$, note that three channels determine the response of the trade balance: i) a value channel - if domestic goods become more expensive relative to foreign the value of exports increases and the value of imports falls; ii) a risk-sharing channel - the term $(2\theta - 1)\sigma$ determines the consumption differential induced by changes in the terms of trade under efficient risk-sharing (approximation to equation (1.10)). If private consumption is home biased and domestic goods become more expensive relative to foreign, efficiency requires that the domestic *consumption level* falls relative to foreign. The stronger the home bias and the intertemporal elasticity of substitution, the larger the fall in the domestic consumption level relative to foreign, and eventually the amount of resources transferred from home to foreign; iii) a substitution channel - the term 20ε reflects that the *composition of consumption goods* also changes in response to a terms of trade appreciation. The higher the home bias and the higher the intratemporal elasticity of substitution, the stronger the expenditure switching from home to foreign goods.

While an increase in the relative price of domestic goods has a positive effect on the trade balance through the value and the risk-sharing channel, it has a negative effect through the substitution channel. Hence, if the effects working through the first two channels dominate the third, the trade balance increases. Note, that home bias in private consumption amplifies both the working of the risk-sharing channel and the substitution channel. If the intertemporal elasticity of substitution, σ , exceeds the intratemporal elasticity of substitution, ε , home and foreign goods are Edgeworth-Pareto complements.¹¹ In this case the home bias will have a stronger effect on the risk-sharing channel than on the substitution channel. As a consequence, if home and foreign goods are complements, an increase in government spending may reduce the trade balance if the home bias in private consumption is small, while the opposite holds for a large home bias in private consumption.¹²

It is useful to relate Result 3 to similar results regarding the international transmission of monetary policy. Tille (2001) considers an economy with incomplete financial markets and without home bias. In this case the sign of the response of the trade balance to a monetary shock depends on the intratemporal elasticity of substitution only, with one being the critical value. Galí and Monacelli (2004) discuss the sign of the relationship between the terms of trade and the trade balance in a small open economy model with complete financial markets and home bias in private consumption. However, the asymmetry between the small open economy and the rest of the world changes the effect of home bias on the risk-sharing channel and the substitution effects. If the elasticity of substitution across different foreign

¹¹ See the discussion in Corsetti and Pesenti (2001) and for a formal derivation Svensson (1987).

¹² An example is given by $\sigma = 5/2$ and $\varepsilon = 3/2$. In this case the trade balance increases if $\theta = 9/10$, while it falls for $\theta = 6/10$.

goods is unity, the trade balance will increase with a terms of trade appreciation if the intertemporal elasticity of substitution exceeds the intratemporal elasticity (Edgeworth-Pareto complements). In contrast to the present model, the degree of home bias does not affect the sign of the trade balance under this assumption.

Note finally that the sign of the response of the trade balance to an government spending shock does not depend on the monetary regime. However, the monetary regime matters for the strength of the response of the terms of trade and therefore indirectly for the quantitative effect of government spending on the trade balance. An accommodating monetary policy dampens the effect of a government spending shock on the trade balance.

1.4.2 Numerical analysis

So far, the analysis has been limited by the assumption that i) government spending shocks are not persistent, ii) international financial markets are complete and iii) the nominal interest rate is adjusted only in response to producer price inflation. These assumptions may appear somewhat restrictive, given that the fiscal shock identified in the data displays a high degree of persistence, that complete financial markets provide full insurance against country-specific shocks and that monetary policy is often characterized by an interest rate feedback rule that responds to consumer price inflation and the output gap. Therefore, the paper investigates whether the above results also hold for persistent shocks to government spending, incomplete financial markets and a characterization of monetary policy by the Taylor rule. The model is solved numerically on the basis of the generalized Schur decomposition as discussed in Klein (2000).

Before turning to the results, parameter values have to be assigned. A time period in the model corresponds to one quarter and β is set to 0.99. The share of government spending is fixed at 20 percent, the long-run average in the data. The degree of autocorrelation in public spending is set to $\rho = 0.9$, which is suitable to capture the persistence of the spending shock identified in the VAR. The share of imports in U.S. GDP is approximately 10 percent in the period 1973 - 2003. Given that government spending falls only on domestic goods in the model, this implies $\theta = 0.875$. The intertemporal elasticity of labor supply is fixed at unity which is somewhere in the middle of the wide range of the values discussed in the literature, see, e.g. Burnside et al. (2004). The price elasticity of demand μ is set to six, implying a steady state mark-up of 10 percent. Regarding the the average frequency of price adjustments, α is set to 0.75 which implies that prices are adjusted on average once a year. To parametrize portfolio costs ψ is set to 0.0074, as in Schmitt-Grohé and Uribe (2003). The coefficients in the interest rate feedback rule (1.15) are set to $\phi_\pi = 1.51$ and $\phi_y = 0.77/4$, i.e. the estimates by Taylor (1993).

In the presence of home bias in private consumption, the relative size of the inter- and intratemporal elasticity of substitution is the key to the response of the trade balance. Unfortunately, there is substantial uncertainty regarding appropriate

values for these elasticities. Regarding the intratemporal elasticity of substitution, ε , takes a value of 0.9 (baseline) corresponding to the estimate reported by Heathcote and Perri (2002). It is also close to the unit elasticity used in Stockman and Tesar (1995) and Corsetti and Pesenti (2001).¹³ Note, however, that Obstfeld and Rogoff (2000) assume a value of six. Given the central role of this parameter, results for the trade balance for $\varepsilon = 1.5$ are reported as well. This corresponds to the baseline value in Backus et al. (1994). The intertemporal elasticity of substitution is assumed to be 1.33, a value slightly above the frequently used unit elasticity. Note, however, that Rotemberg and Woodford (1997) estimate the intertemporal elasticity of substitution to be around 6, while Patterson and Pesaran (1992) report a value of 0.2.

Figure 3 displays the response of key variables to a temporary increase in government spending. In the baseline case international financial markets are incomplete, monetary policy follows a Taylor rule and the intertemporal elasticity of substitution exceeds the intratemporal elasticity of substitution such that home and foreign goods are Edgeworth-Pareto complements (solid line). Three alternatives are considered, where, in turn, one feature of the baseline case is altered. First, in order to assess the role of monetary policy, the case of producer price stability is considered. Note that, as argued above, the resulting allocation would prevail under price flexibility (dotted line). Next, in order to assess the role of international financial markets, the case of complete risk sharing across both countries is considered as well (broken line). Using this assumption the analytical results have been derived above. Finally, the intratemporal elasticity of substitution is set to 1.5 such that it exceeds the intertemporal elasticity of substitution (starred line).

The exogenous shock to government spending is displayed in panel a). Panel b) shows the response of output with an impact multiplier of around 0.7. This is quantitatively within the range of what is found in the data. Consumer prices fall on impact but increase from the second quarter onwards (panel c)). In the case of producer price stability, the consumer price level falls throughout as a result of complete exchange rate pass-through. A comparison of the baseline response and response in the price stability case indicates that the Taylor rule implies a relatively accommodating monetary policy stance. It also depreciates the nominal exchange rate and the terms of trade *relative to* the flexible price allocation (panel d) and e)). In absolute terms the nominal exchange rate depreciates after 12 quarters in all cases except the price stability case. Finally, in all cases except where the intratemporal elasticity of substitution takes the value of $\varepsilon = 1.5$, net exports increase in response to a government spending shock (panel f)).

Hence, the numerical analysis confirms the analytical results derived above. In addition, it illustrates that relaxing the assumption of complete financial markets does not alter the results derived under complete risk sharing. The role of monetary

¹³Note that Cole and Obstfeld (1991) show that under the assumption of a unit elasticity between home and foreign goods the structure of international asset markets does not matter for the equilibrium outcome.

policy as accommodating relative to the flexible price allocation is confirmed as well as the role of size of the intra- and intertemporal elasticity of substitution for the response of the trade balance. Finally, comparing the VAR responses (figure 1) and the model responses (figure 3) reveals that the model lacks the ability to match quantitatively the VAR responses of the variables of interest, while it goes some way in accounting for the responses in a qualitative way.

1.5 Conclusion

This paper has tried to establish empirically the dynamic effects of an exogenous increase in government spending on the nominal exchange rate, the terms of trade and the trade balance. The main finding proves to be robust across various VAR specifications: the exchange rate depreciates, the terms of trade appreciate and the trade balance moves into surplus after an exogenous increase in government spending.

The strong and significant responses of the terms of trade provide a guideline for the theoretical exploration of the empirical findings. Specifically, the paper investigated whether a stochastic general equilibrium model with price rigidities can account for the evidence, and if so under what conditions. It turns out that, independently of the monetary stance during the transmission process, an exogenous increase in government spending increases the trade balance if both the intertemporal elasticity of substitution exceeds the intratemporal elasticity of substitution and there is a strong home bias in private consumption. The reason is as follows: under the assumption that government spending falls entirely on home goods, an increase in government spending induces an appreciation in the terms of trade such that home goods become more expensive relative to foreign goods. In the presence of home bias and complete risk sharing, a high intertemporal elasticity of substitution induces a large fall in the domestic level of consumption relative to foreign, while a low intertemporal elasticity of substitution induces only small substitution effects from home to foreign goods. Hence, resources are transferred from home to foreign and net exports increase.

Monetary policy, which is characterized by an interest rate feedback rule, does not alter but dampens the effect on net exports, because it accommodates the increase in government spending relative to the flexible price allocation. A loose monetary stance is also reflected in the depreciation of the nominal exchange rate.

This interpretation of the dynamic effects of government spending on foreign trade, allows to draw a tentative conclusion regarding the recent U.S. fiscal expansion. Contrary to widely held views, an *exogenous* increase in government spending may not have necessarily contributed to the U.S. trade deficit.¹⁴ On the other hand,

¹⁴Using a richer calibrated two-country model, Erceg, Guerrieri and Gust (2005) also find that while the recent stimulative fiscal policy in the U.S. may have contributed to the trade deficit, its quantitative role have been quite modest. Also Kollmann (1998) comparing the role of fiscal policy and productivity in determining the U.S. trade balance from 1975 to 1991 finds a very limited role

a fairly accommodating monetary policy may have reduced the possible *positive* effects on the trade balance. Hence, the current and also former episodes in U.S. time series when high government spending and trade deficits occurred simultaneously may not simply stem from expansionary fiscal policy. Alternative explanations may instead focus on endogenous components in fiscal policy. Also the recent U.S. fiscal expansion is in large parts the result of tax cuts, which have not been investigated in the present paper. Further investigations into these issues appear to be promising.

Moreover, while the degree of home bias in private consumption may be calibrated confidently using first moments of the data, there is little agreement in the literature regarding the relative size of the intra- and intratemporal elasticities of substitution. Finally, it may be instructive to establish more evidence using data for smaller countries, where government spending may have little impact on the terms of trade. Lane and Perotti (2003), for example, use a small country model and suggest that fiscal expansions induce a loss in competitiveness as costs increase while prices are fixed on world markets. In this scenario, a trade deficit rather than a surplus might be the effect of a fiscal expansion.

for government spending.

1.6 Appendix

Log-linearized model Small letters denote the log-deviation of a variable from its steady state value, where the latter is referred to by dropping the subscript "t". Given an initial steady state with balanced trade and a zero net foreign asset position, an exogenous process for domestic government spending g_t and the flex-price output levels y_t^f and y_t^{f*} , the following sequence is considered:

$$\left\{ \pi_{H,t}, \pi_{H,t}^*, \pi_{F,t}, \pi_{F,t}^*, \pi_t, \pi_t^*, \tau_t, \tau_t^*, c_t, c_t^*, y_t, y_t^*, \Delta s_t, \tau_t, \hat{t}b_t, \hat{b}_{F,t} \right\}_{t=0}^{\infty}.$$

where $\pi_t = \log(P_t/P_{t-1})$, $\tau_t = \log(P_{F,t}/P_{H,t})$, $\hat{t}b_t = TB_t/Y$ and $\hat{b}_{F,t+1} = B_{F,t}/Y$. It satisfies the following conditions/definitions. First, symmetric conditions in home and foreign are considered. The Euler equation (1.9) and its foreign equivalent approximated by

$$c_t = E_t c_{t+1} - \sigma(r_t - E_t \pi_{t+1}), \quad c_t^* = E_t c_{t+1}^* - \sigma(r_t^* - E_t \pi_{t+1}^*), \quad (1.16)$$

where $\sigma = -u'/u''C$ measures the intertemporal elasticity substitution. A log-linear approximation to (1.13) gives a variant of the New Keynesian Phillips Curve,

$$\pi_{H,t} = \beta E_t \pi_{H,t+1} + \kappa((1-\theta)\tau_t + \omega y_t + \sigma c_t), \quad (1.17)$$

$$\pi_{F,t}^* = \beta E_t \pi_{F,t+1}^* + \kappa(-(1-\theta)\tau_t + \omega y_t^* + \sigma c_t^*), \quad (1.18)$$

where $\kappa = (1-\alpha)(1-\alpha\beta)/(\alpha(1+\mu\omega))$ and $\omega = v'/v''H$ measures the intertemporal elasticity of supply of differentiated output. Consumer price inflation implied by (1.2) is approximated as

$$\pi_t = \theta\pi_{H,t} + (1-\theta)\pi_{F,t}, \quad \pi_t^* = \theta\pi_{F,t}^* + (1-\theta)\pi_{H,t}^*. \quad (1.19)$$

Linearizing the law of one price (1.3) and taking first differences gives

$$\pi_{H,t} = \Delta s_t + \pi_{H,t}^*, \quad \pi_{F,t} = \Delta s_t + \pi_{F,t}^*. \quad (1.20)$$

The good market clearing conditions are approximated as

$$y_t = \theta(1-g)c_t + (1-\theta)(1-g)c_t^* + gg_t + 2\varepsilon\theta(1-g)(1-\theta)\tau_t, \quad (1.21)$$

$$y_t^* = \theta(1-g)c_t^* + (1-\theta)(1-g)c_t - 2\varepsilon\theta(1-g)(1-\theta)\tau_t. \quad (1.22)$$

The interest rate feedback rules (1.15) can be conveniently written as

$$r_t = \phi_\pi \pi_t + \phi_y (y_t - y_t^f), \quad r_t^* = \phi_\pi \pi_t^* + \phi_y (y_t^* - y_t^{f*}). \quad (1.23)$$

A second set of conditions/definitions reflects the interdependence between home and foreign. The trade balance (1.6) is approximated as

$$\frac{1}{(1-\theta)(1-g)}\hat{t}b_t = (2\varepsilon\theta - 1)\tau_t - (c_t - c_t^*) \quad (1.24)$$

and the terms of trade (1.4) imply the following log-linear dynamic relationship

$$\tau_t = \tau_{t-1} + \pi_{F,t} - \pi_{H,t}. \quad (1.25)$$

Finally, under complete international financial markets an approximation to the cross-country risk sharing condition (1.10) has to hold and the risk-less bond is redundant,

$$(c_t - c_t^*) = \sigma (2\theta - 1) \tau_t, \quad \dot{b}_{F,t} = 0. \quad (1.26)$$

On the other hand, if international financial markets are incomplete, the linearized domestic budget constraint (1.11) serves to characterize the equilibrium

$$\beta \dot{b}_{F,t+1} = \dot{b}_{F,t} + y_t - (1 - g) c_t - gg_t - (1 - g) (1 - \theta) \tau_t, \quad (1.27)$$

as well as the condition

$$\tau_t - \tau_t^* = \Delta s_{t+1} - \psi Y \dot{b}_{F,t+1}, \quad (1.28)$$

obtained from linearizing (1.12) and subtracting the linearized Euler equation (1.9). The budget constraint of the foreign country is redundant by Walras' law.

Result 1 (Flexible price allocation) Formally, producer price stability implies that instead of (1.23) the following holds

$$\pi_{H,t} = 0, \quad \pi_{F,t}^* = 0. \quad (1.29)$$

Imposing these conditions on (1.17) and (1.18), respectively, and subtracting gives

$$0 = 2(1 - \theta) \tau_t^f + \omega^{-1} y_t^{fD} + \sigma c_t^{fD}, \quad (1.30)$$

where a superscript "D" denotes the difference between home and foreign. Imposing the risk-sharing condition (1.26) gives

$$y_t^{fD} = -\omega \tau_t^f. \quad (1.31)$$

Subtracting the goodmarket clearing condition for the foreign good (1.22) from its home counterpart (1.21) and imposing the risk-sharing condition (1.26) gives

$$y_t^{fD} = \left[4\varepsilon\theta(1 - g)(1 - \theta) + \sigma(2\theta - 1)^2(1 - g) \right] \tau_t^f + gg_t. \quad (1.32)$$

Combining (1.31) and (1.32) gives the solution for the terms of trade in the flex-price case

$$\tau_t^f = -\frac{g}{\xi} g_t, \quad (1.33)$$

where

$$\xi \equiv \omega + 4\varepsilon\theta(1 - g)(1 - \theta) + \sigma(2\theta - 1)^2(1 - g) \quad (1.34)$$

is unambiguously positive. Extending (1.3) with $P_{H,t}$ and considering log-deviations gives

$$s_t = \tau_t + p_{H,t} - p_{F,t}^*, \quad (1.35)$$

such that in the price stability case, the nominal exchange rate displays the same dynamics as the terms of trade

$$s_t^f = \tau_t^f = -\frac{g}{\xi} g_t. \quad (1.36)$$

To solve for the natural interest rate differential, i.e. difference in the real interest rate between home and foreign, I subtract the foreign Euler equation from home (1.39), impose risk sharing condition (1.26) and the fact that $E_t g_{t+1} = 0$ together with (1.36) in order to obtain

$$\hat{r}_t^f = (2\theta - 1) \frac{g}{\xi} g_t. \quad (1.37)$$

Result 2 (Sticky price allocation) Monetary policy is characterized by the feedback rule

$$r_t = \phi_\pi \pi_{H,t}, \quad r_t^* = \phi_\pi \pi_{F,t}^*. \quad (1.38)$$

Taking the difference of the Euler equations (1.16) and imposing the risk sharing condition (1.26) and together with (1.38) gives

$$\tau_t + \phi_\pi \hat{\pi}_t^D = E_t \tau_{t+1} + E_t \hat{\pi}_{t+1}^D. \quad (1.39)$$

Subtracting the Phillips Curves (1.18) and (1.17) from each other and imposing the risk sharing (1.26) and the goodsmarket clearing conditions (1.21), (1.22) gives

$$\hat{\pi}_t^D = \beta E_t \hat{\pi}_{t+1}^D + \kappa \omega^{-1} \xi \tau_t + \kappa \omega^{-1} g g_t, \quad (1.40)$$

where $\hat{\pi}_t^D \equiv \pi_{H,t} - \pi_{F,t}^*$ denotes the difference between home and foreign producer price inflation. Equations (1.39) and (1.40) define a linear system of expectational difference equations with two endogenous forward-looking variables

$$\underbrace{\begin{bmatrix} 1 & 1 \\ \beta & 0 \end{bmatrix}}_{=:A} \underbrace{\begin{bmatrix} E_t \hat{\pi}_{t+1}^D \\ E_t \tau_{t+1} \end{bmatrix}}_{=:B} = \underbrace{\begin{bmatrix} \phi_\pi & 1 \\ 1 & -\kappa \omega^{-1} \xi \end{bmatrix}}_{=:B} \underbrace{\begin{bmatrix} \hat{\pi}_t^D \\ \tau_t \end{bmatrix}}_{=:C} + \underbrace{\begin{bmatrix} 0 \\ -\kappa \omega^{-1} g \end{bmatrix}}_{=:C} g_t. \quad (1.41)$$

If both eigenvalues of $\Omega^{-1} = A^{-1}B$ are outside the unit circle the rational expectations equilibrium is determinate. This will be the case if ϕ_π exceeds unity. To see this note that

$$\det \Omega^{-1} = (1 + \phi_\pi \kappa \omega^{-1} \xi) / \beta \text{ and } \text{tr } \Omega^{-1} = 1 + (1 + \kappa \omega^{-1} \xi) / \beta \quad (1.42)$$

such that, if $\phi_\pi > 1$,

$$\det \Omega^{-1} + \text{tr } \Omega^{-1} > -1 \text{ and } \det \Omega^{-1} - \text{tr } \Omega^{-1} > -1, \quad (1.43)$$

which is sufficient for both eigenvalues being outside the unit circle, see Woodford (2003, Add. to Ch. 4). In a closed economy the condition $\phi_\pi > 1$ has been identified as the Taylor principle, see Woodford (2001). Rewriting (1.41) as

$$\begin{bmatrix} \dot{\pi}_t^D \\ \tau_t \end{bmatrix} = \Omega E_t \begin{bmatrix} \dot{\pi}_{t+1}^D \\ \tau_{t+1} \end{bmatrix} - \Gamma g_t, \quad (1.44)$$

where $\Gamma := B^{-1}C$, and solving forward using the law of iterated expectations and the properties of Ω^{-1} (implying $\lim_{T \rightarrow \infty} \Omega^T = 0$), gives

$$\begin{bmatrix} \dot{\pi}_t^D \\ \tau_t \end{bmatrix} = - \sum_{k=0}^{\infty} \Omega^k \Gamma E_t \{g_{t+k}\}. \quad (1.45)$$

Under the assumption that there is no persistence in the exogenous shock, i.e. if $\rho = 0$, the solution for the producer price inflation differential and the terms of trade is given by

$$\begin{bmatrix} \dot{\pi}_t^D \\ \tau_t \end{bmatrix} = -\Gamma g_t = \frac{\kappa\omega^{-1}g}{\phi_\pi\kappa\omega^{-1}\xi + 1} \begin{bmatrix} 1 \\ -\phi_\pi \end{bmatrix} g_t. \quad (1.46)$$

Rewriting gives for the terms of trade

$$\tau_t = -\frac{g}{\xi + \omega/(\kappa\phi_\pi)} g_t. \quad (1.47)$$

Next, consider the response of the nominal exchange rate. Taking the first difference of (1.35) gives

$$\Delta s_t = \tau_t - \tau_{t-1} + \dot{\pi}_t^D. \quad (1.48)$$

Using the solution for the inflation differential and the terms of trade and the fact that the economy is initially in steady state, the initial response of the exchange rate, s_1 , to a spending shock is given by

$$s_1 = -\frac{\phi_\pi - 1}{\phi_\pi} \frac{g}{\xi + \omega/(\kappa\phi_\pi)} g_1, \quad (1.49)$$

whereas from the second period onwards it stays permanently at the new level

$$\bar{s} = \frac{1}{\phi_\pi} \frac{g}{\xi + \omega/(\kappa\phi_\pi)} g_1. \quad (1.50)$$

To solve for the interest rate differential, \hat{r}_t , first consider the difference in consumer price inflation, given by

$$\pi_t^D = \theta\pi_{H,t} + (1-\theta)\pi_{F,t} - (1-\theta)\pi_{H,t}^* - \theta\pi_{F,t}^*, \quad (1.51)$$

substitute for foreign consumer price inflation using the law of one price (1.20) and for the nominal exchange rate using (1.48) to obtain

$$\pi_t^D = \dot{\pi}_t^D + 2(1-\theta)\Delta\tau_t. \quad (1.52)$$

The real interest rate differential is given by the difference in the nominal interest rates less the difference in the expected consumer price inflation. Given that $E_t \dot{\pi}_{t+1}^D = 0$ and $E_t \tau_{t+1} = 0$ this implies after substituting for $\dot{\pi}_t^D$ and τ_t

$$\tilde{r}_t = \frac{(2\theta - 1)g}{\xi + \omega/(\kappa\phi_\pi)} g_t. \quad (1.53)$$

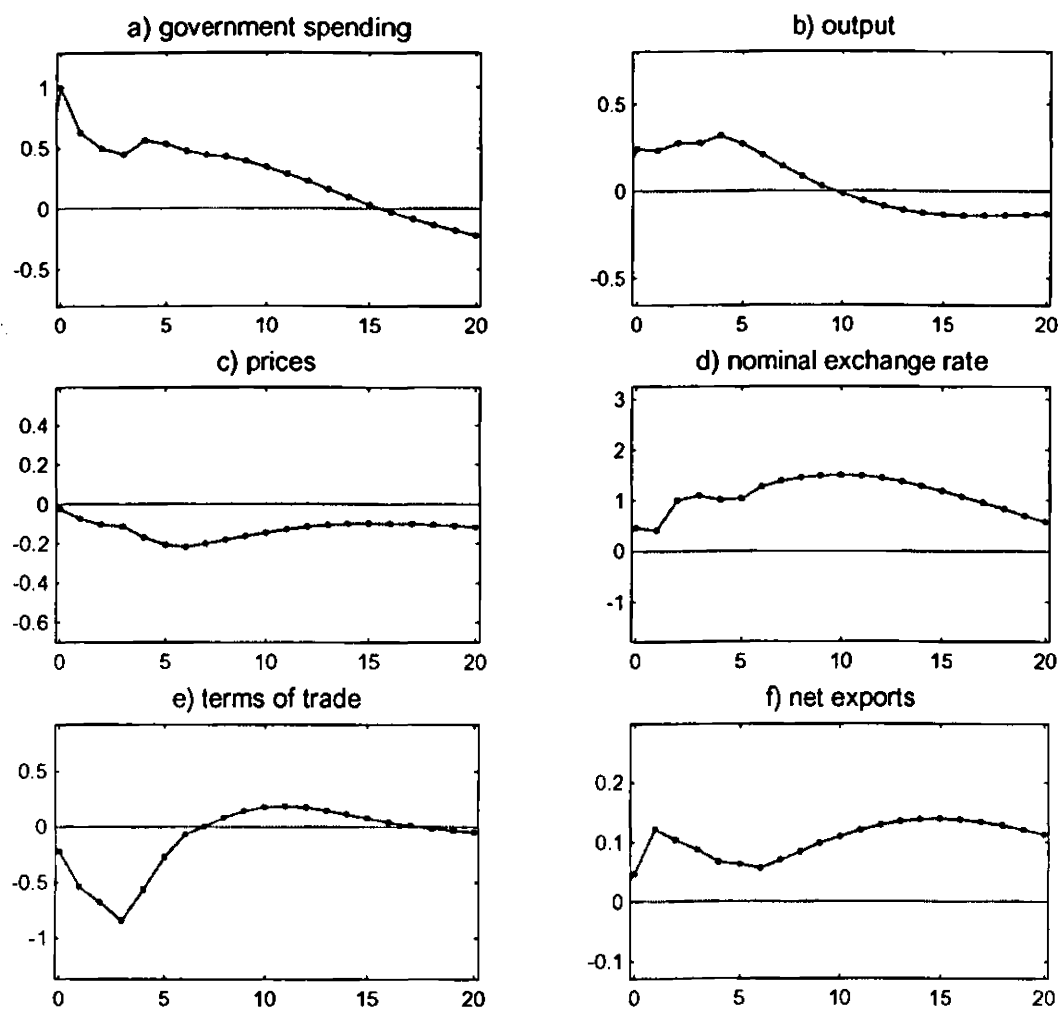
Result 3 (Trade balance) First, consider the flex price allocation. Imposing (1.26) and (1.33) on (1.24) gives

$$\frac{1}{(1-\theta)(1-g)} \hat{b}_t = [(2\theta - 1)\sigma + 1 - 2\varepsilon\theta] \frac{g}{\xi} g_t. \quad (1.54)$$

In the sticky price case, imposing (1.26) and (1.47) on (1.24) gives

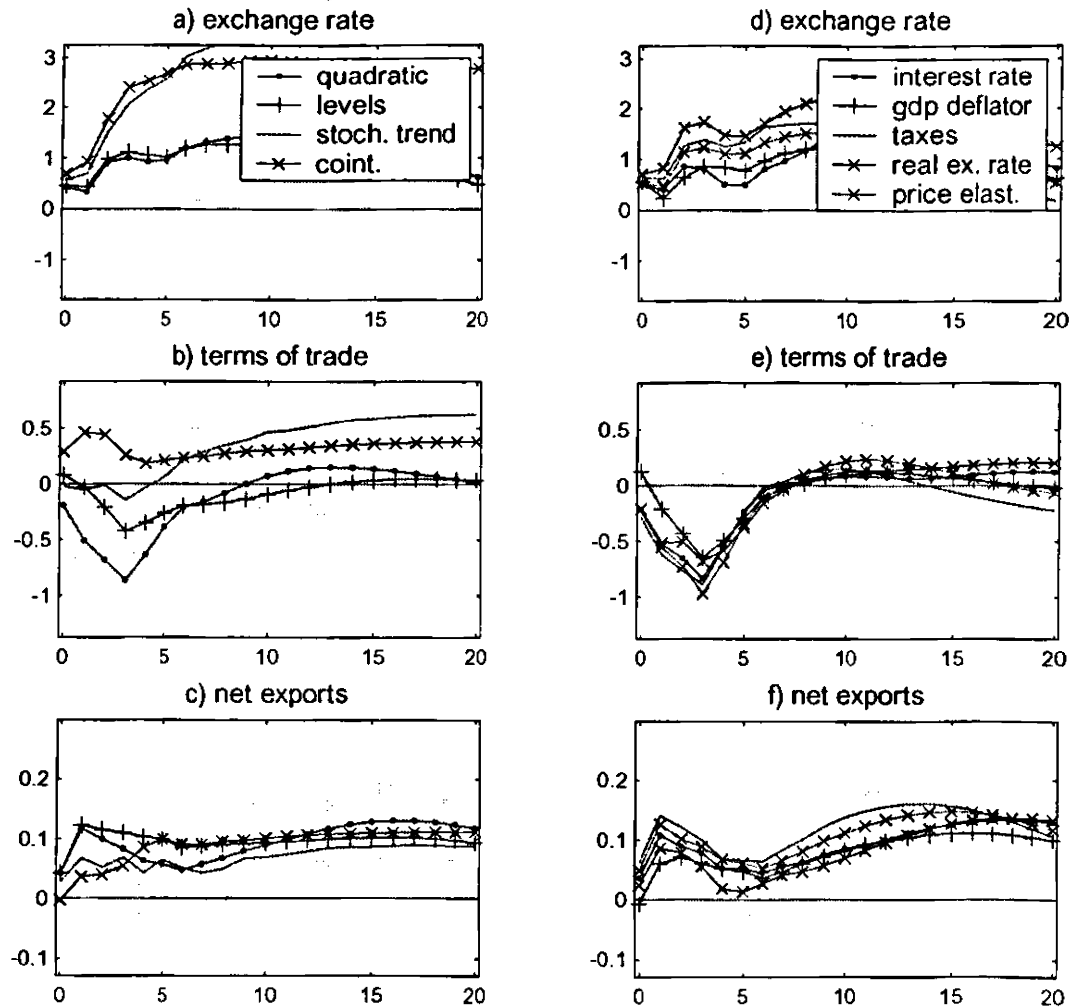
$$\frac{1}{(1-\theta)(1-g)} \hat{b}_t = [(2\theta - 1)\sigma + 1 - 2\varepsilon\theta] \left(\frac{g}{\xi + \omega/(\kappa\phi_\pi)} \right) g_t. \quad (1.55)$$

Figure 1: Dynamic Effects of U.S. Government Spending Shock



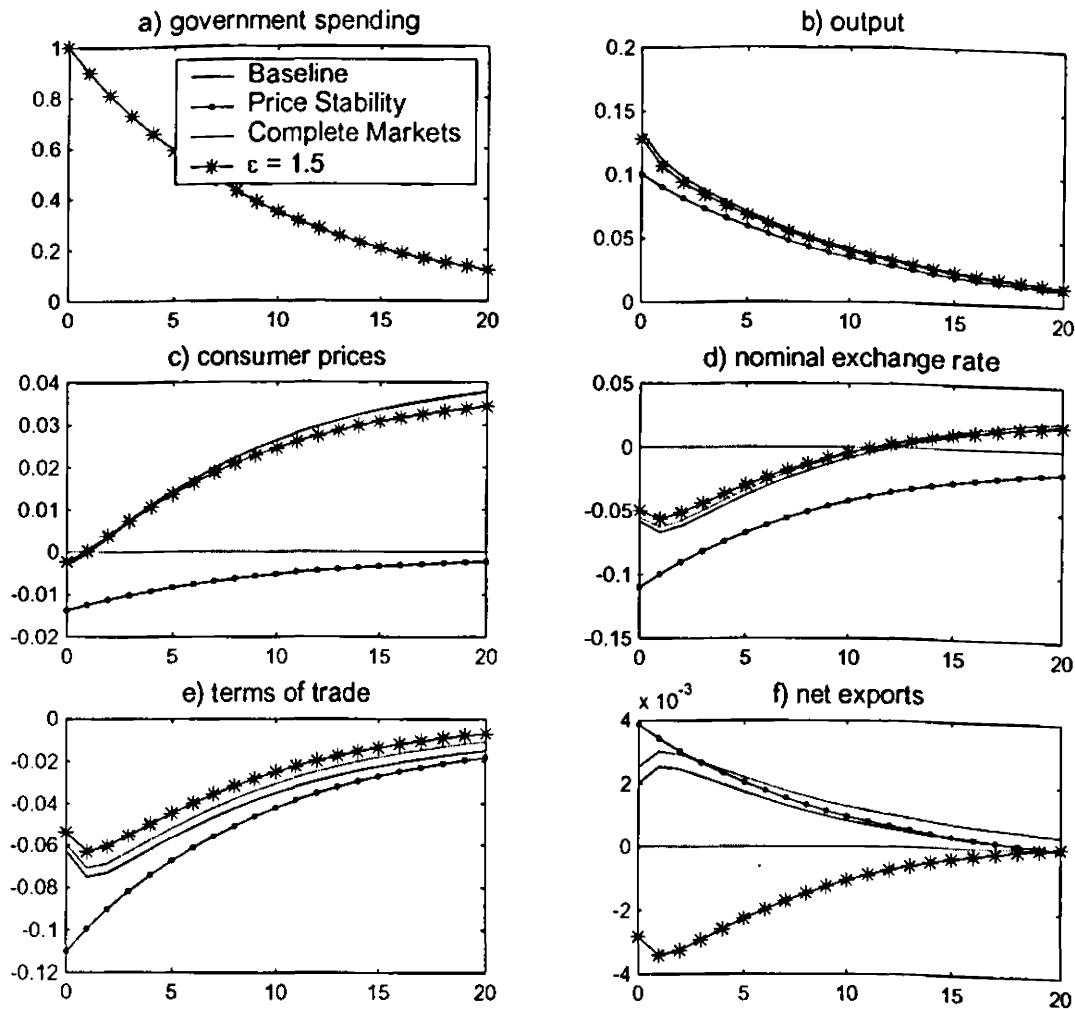
Legend: VAR-based impulse responses to a one percent increase in government spending (1973:1-2003:4). Shaded areas indicate bootstrapped 95 percent confidence intervals. Vertical axes indicate deviations from unshocked path. Net exports: percentage points of GDP. Other variables: percent. Horizontal axes indicate quarters.

Figure 2: Robustness of VAR-Results



Legend: VAR-based impulse responses to a one percent increase in government spending (1973:1-2003:4). Shaded areas indicate bootstrapped 95 percent confidence intervals. Panel a)-c): alternative trend specifications. Panel d)-f): alternative/additional variables in VAR.

Figure 3: Effects of Spending Shock in Two-Country Model



Chapter 2

Fleshing out the Monetary Transmission Mechanism: Output Composition and the Role of Financial Frictions (with André Meier)

2.1 Introduction

The last two decades have seen a tremendous body of work attempting to characterize empirically the transmission of monetary policy shocks based on structural Vector Autoregressions (VAR). In light of the contributions by Christiano, Eichenbaum and Evans (1999), Woodford (2003) and others, it seems fair to speak of an emerging consensus on the basic pattern of the economy's response to a monetary policy shock. Nonetheless, the precise channels of transmission and their relative importance have remained a topic of debate. In particular, it is largely unclear whether or not there is a significant channel of transmission above and beyond the classical interest rate channel. One serious candidate is provided by the literature on financial frictions. In fact, imperfect information in loan markets can make borrowing conditions a function of borrowers' net worth, giving rise to a "balance sheet channel" that tends to reinforce the impact of a given monetary shock. A formal model of such a "financial accelerator" was provided by Bernanke, Gertler and Gilchrist (1999), henceforth BGG. Despite some suggestive evidence, however, the quantitative relevance of this feature is still an open question.

In the present paper, we thus focus on the role of financial frictions for the responses of output, consumption and investment to a monetary policy shock. Specifically, we start from the VAR-based evidence and relate it to the predictions of a Dynamic Stochastic General Equilibrium (DSGE) model with nominal rigidities.

Our model encompasses several features that are commonly considered in the literature but additionally allows for financial frictions in line with BGG. We take this model to the data using a minimum distance strategy similar to Rotemberg and Woodford (1997) and Christiano, Eichenbaum and Evans (2005), henceforth CEE.

Our motivation is twofold. First, given the profession's interest to work with empirically successful yet parsimonious models, it is a critical task to establish the relative importance of different features on the real side and on the nominal side of New Keynesian models. For an example of the latter, consider the challenge of establishing whether nominal rigidities are more relevant in wage setting or in price setting, as has been investigated, for example, by CEE. On the real side, the financial accelerator is but one of the features that should be examined more thoroughly. As Woodford (2003, p.11) puts it, "there is no substitute for careful empirical research to flesh out the details of a quantitatively realistic account of the monetary transmission mechanism." Second, better insights into the nature of monetary transmission have obvious benefits for policy-making. In this context, the microfoundations of the financial sector may seem of particularly topical importance insofar as the new Basel Capital Accord is expected to affect the sensitivity of financing costs with respect to the borrower's balance sheet quality.

Given that economic interest centrally bears on the impulse responses associated with a monetary policy shock, it is natural to consider this statistic as the critical nexus between theory and data. Consequently, we seek to obtain estimates for the structural parameters of our model by matching the impulse response functions estimated from US data (1980:1-2003:4) with those implied by the model.

The idea of estimating a DSGE model with a minimum distance approach goes back to Rotemberg and Woodford (1997).¹ Their small-scale New Keynesian model included only output, inflation and the nominal interest rate. The model was subsequently extended by Amato and Laubach (2003), who also included wage inflation; Boivin and Giannoni (2003), who allowed for the indexation of prices; and Giannoni and Woodford (2003), who combined both assumptions. CEE use a medium-scale model that incorporates price and wage rigidities and also allows for a richer specification of the real side of the economy, taking investment and capital utilization into account.

In contrast to CEE, we highlight the possible role of financial frictions in the transmission of monetary policy shocks. In doing so, we rely on the theoretical work of BGG who introduced a financial accelerator into the DSGE framework. Because financial frictions have distinct implications for the behavior of individual output components, our analysis considers not only aggregate output, as has been common practice in the literature, but also looks at the specific responses of consumption and investment. Indeed, compositional effects are likely to contain important information

¹Some alternative ways of estimating DSGE models have been put forward recently. Altig et al. (2005) extend the methodology of CEE, using several shocks instead of relying on the monetary policy shock only. Full-information techniques have also been suggested. Ireland (2004), for instance, uses classical maximum likelihood methods to estimate a New Keynesian model, while Smets and Wouters (2004) apply Bayesian methods.

on the nature of monetary transmission, as has also been argued in a recent paper by Angeloni et al. (2003). These authors note striking compositional differences in the impulse responses for US and EU area data that cannot be fully explained by the structural features of prominent DSGE models. However, the models considered by Angeloni et al. (2003), i.e. CEE and Smets and Wouters (2003), do not feature the sort of financial accelerator effects we are set to study.

Christiano, Motto and Rostagno (2003), in another related paper, account for financial frictions in analyzing the origins of the Great Depression. Overall, their model performs well and replicates several key features of the historical data. However, the paper does not isolate the precise contribution of financial frictions to the transmission of a given shock, although the authors emphasize that this would provide crucial information for future model development. Our own paper attempts to provide this additional insight with respect to the transmission of monetary policy shocks.

Lastly, our econometric approach aims to extend the work of Rotemberg and Woodford and CEE by using a different, more efficient weighting scheme. This addresses the criticism by Schorfheide (2003) that previous examples of minimum distance estimation have not sufficiently taken into account dependencies between impulse responses across periods and series. Apart from promising more precise estimates, our approach also lends itself nicely to comparative model evaluation. Specifically, we provide distance metric tests to examine the relative fit of several restricted models which are nested in our most general specification.

The remainder of this paper is structured as follows. In section 2, we introduce the details of our model, i.e. the stylized economy for which we compute theoretical impulse responses. Section 3 looks at the empirical counterpart, presenting our data, our VAR model and the associated impulse responses. Section 4 contains a detailed description of our estimation strategy. Our results are provided in section 5, and section 6 concludes. The discussion of less instructive technicalities as well as all tables and figures are relegated to the appendix.

2.2 The Model

The model we consider features a financial accelerator in the framework of a DSGE model with monopolistic competition and nominal rigidities. The way we model the financial accelerator largely follows BGG. However, to their exposition we add a few features that allow for richer dynamics of the model in response to a monetary policy shock. The model distinguishes households, entrepreneurs, retailers and a central bank, whose monetary policy is characterized by an interest feedback rule. Households are infinitely-lived and choose consumption intertemporally and intratemporally over differentiated goods provided by retailers. Our specification of preferences allows for internal habit formation in consumption as in Amato and Laubach (2004). Further, households provide differentiated labor services to entrepreneurs and set wages in a staggered fashion à la Calvo. Entrepreneurs hire labor

and combine it with capital to produce wholesale output in a fully competitive environment. In order to introduce monopolistic competition in the goods market, the model comprises a retail sector. Retailers buy wholesale output from entrepreneurs and transform it into differentiated goods which are then sold on to households for consumption purposes and to the entrepreneur sector for the production of capital goods. Retailers face downward sloping demand functions and also set prices à la Calvo.

Before we describe the objectives and constraints of all agents in greater detail, the role of the entrepreneur sector should be highlighted. This sector is, in fact, the key for the working of the financial accelerator. Entrepreneurs are risk-neutral and have a finite horizon. Because entrepreneurs are different from households, the model does not collapse into a representative agent framework, so borrowing and lending is possible in equilibrium. Financial frictions arise from asymmetric information in the relationship between borrowers (i.e. entrepreneurs) and lenders (i.e. a financial intermediary who ultimately represents households and thus need not be modeled explicitly). Specifically, lenders are assumed to face positive costs in the case they decide to audit a debtor's economic performance. To minimize resources lost in monitoring, lenders will only do this when the borrower declares himself unable to honor his contractual obligations, i.e. in a situation of (supposed) financial distress. Hence, auditing costs in the model should be interpreted as proxying for all kinds of expenses associated with debtor bankruptcy, such as accounting and legal expenses or losses arising from asset liquidation. These costs cause loans to be traded at a premium over the risk-free rate and give an important role to borrowers' balance sheet conditions. In particular, if entrepreneurial wealth is small with respect to the total amount of financing required, bankruptcy is more likely and expected default costs rise. As a consequence, borrowers must pay a relatively high premium in equilibrium to compensate lenders. This mechanism has interesting implications for the propagation of shocks and the cyclicity of investment, spending and output. Specifically, to the extent that a recession depresses entrepreneurial net worth, say by causing a decline in asset prices, it automatically triggers a rise in the external finance premium, too. The countercyclical behavior of the finance premium tends to amplify swings in borrowing and lead to deeper fluctuations of real activity. Likewise, monetary policy shocks have more pronounced effects in that interest rate hikes, which already create more precarious business conditions, simultaneously raise the risk premium. One of the goals of our paper is to rigorously assess the quantitative importance of this mechanism. To do so, we now turn to a more formal presentation.

2.2.1 Aggregation of Final Goods

Final goods Y_t - used for consumption and investment - are bundles of differentiated goods $Y_t(z)$, $z \in [0, 1]$, which are provided by a continuum of monopolistically

competitive retailers. The usual Dixit-Stiglitz aggregator reads as

$$Y_t = \left[\int_0^1 Y_t(z)^{\frac{\epsilon}{\epsilon-1}} dz \right]^{\frac{\epsilon-1}{\epsilon}}. \quad (2.1)$$

The optimal allocation of expenditure across differentiated goods implies a downward sloping demand function for a generic good z ,

$$Y_t(z) = \left(\frac{P_t(z)}{P_t} \right)^{-\epsilon} Y_t, \quad (2.2)$$

where $P_t(z)$ denotes the price of good $Y_t(z)$ and ϵ measures the price elasticity of demand among differentiated goods. P_t denotes the price index of final goods given by

$$P_t = \left[\int_0^1 P_t(z)^{1-\epsilon} dz \right]^{\frac{1}{1-\epsilon}}. \quad (2.3)$$

2.2.2 Retailers

Retailers purchase wholesale output from entrepreneurs and transform it into differentiated goods using a linear technology. This has two implications. First, up to a first-order approximation, the amount of final goods varies one-for-one with the amount of wholesale goods in the economy. Second, nominal marginal costs in the retail sector are equal to the price of wholesale output, P_t^w .

Retailers set prices to maximize profits, but their ability to do so is constrained exogenously. Specifically, in a discrete time version of Calvo (1983), we assume that each retailer can reoptimize his price in a given period with probability $1 - \theta_p$, independently of other firms and of the time elapsed since the last adjustment. The law of large numbers implies that a fraction $1 - \theta_p$ of retailers reoptimize their prices each period. During the intervals between reoptimizations, individual prices are partially indexed to lagged inflation, where κ_p governs the degree of indexation. Consequently, if the price for good z has not been reoptimized for k periods, it is given by $P_{t+k}(z) = P_t(z) (P_{t+k-1}/P_{t-1})^{\kappa_p}$. Indexation rules of this type have been suggested as a simple way to account for inertia in the observed inflation response to a monetary shock. In line with Rotemberg and Woodford (1997) and BGG, we also assume that price setting occurs prior to the realization of any aggregate time t disturbance. Therefore, if reoptimization is possible, a generic retailer z will set P_t^* in order to maximize

$$E_{t-1} \sum_{k=0}^{\infty} \left[\theta_p^k \Delta_{t,k} \frac{P_t^* (P_{t+k-1}/P_{t-1})^{\kappa_p} - P_{t+k}^w}{P_{t+k}} Y_{t,t+k}(z) \right] \quad (2.4)$$

subject to the demand function (2.2). $Y_{t,t+k}(z)$ denotes the sales of retailer z in period $t+k$, if the most recently optimized price came into effect in period t . Note that future profits are discounted at rate $\theta_p^k \Delta_{t,k}$, where $\Delta_{t,k}$ stands for the intertemporal

marginal rate of substitution of households, who own the retail firms. The factor θ_p^k gives the probability that prices will not be reoptimized for k periods. The solution to the above maximization problem satisfies the first-order condition

$$E_{t-1} \left\{ \sum_{k=0}^{\infty} \theta_p^k \Delta_{t,k} Y_{t,t+k}(z) \left[\frac{P_t^* (P_{t+k-1}/P_{t-1})^{\kappa_p}}{P_{t+k}} - \frac{\epsilon}{\epsilon-1} X_{t+k} \right] \right\} = 0, \quad (2.5)$$

where $X_t = P_t^w/P_t$ denotes the relative price of wholesale output in terms of final output, our numeraire. X_t thus provides a measure for the real marginal costs facing retailers. If all retailers are able to reoptimize prices each period, i.e. if $\theta_p = 0$, prices are set to maintain a constant markup over expected nominal marginal costs: the optimality condition (2.5) simplifies to $P_t^* = [\epsilon/(\epsilon-1)] E_{t-1} P_t^w$. The size of the markup naturally depends on ϵ , the price elasticity of demand among differentiated goods. If instead $0 < \theta_p < 1$, log-linear approximations² of (2.5) and the aggregate price index (2.3) imply the following relationship between inflation, defined as $\pi_t = \log(P_t/P_{t-1})$, and real marginal costs x_t :

$$E_{t-1} (\pi_t - \kappa_p \pi_{t-1}) = \beta E_{t-1} (\pi_{t+1} - \kappa_p \pi_t) + \lambda_p E_{t-1} x_t, \quad (2.6)$$

where $\lambda_p = (1 - \theta_p)(1 - \beta\theta_p)/\theta_p$ and β denotes the households' discount factor. Note that (2.6) is a variant of the so-called New Keynesian Phillips Curve. Abstracting from the issue of indexation, inflation can be seen to respond both to expected future inflation and to pressures stemming from current marginal cost.

2.2.3 Entrepreneurs

The entrepreneur sector, in which the financial accelerator originates, is modeled largely as in BGG. Entrepreneurs hire labor and combine it with purchased capital to produce wholesale output. In contrast to retailers, they operate in a fully competitive environment. Entrepreneurs have a finite horizon, and a fraction $1 - \iota$ exits business in each period. This assumption is meant to capture the phenomenon of ongoing births and deaths of firms. At the same time, it guarantees that entrepreneurs remain dependent on external funds. When they exit business, entrepreneurs' equity is transferred to households.³

²In the following, we rely on log-linear approximations around a non-stochastic steady state. Small letters are used to denote the log deviation of a variable from its steady-state value, e.g. $x_t = \log(X_t/X)$. Note that variables without time subscripts refer to steady-state values.

³This assumption mimics the setup in Christiano, Motto and Rostagno (2003) and avoids introducing a distinct category of entrepreneurs' consumption as in BGG. Consequently, our model has the desirable property that consumption is solely governed by the intertemporal optimization of households and does not include a separate consumption term which would arise as an artifact of the heterogeneous agents setup. In order to ensure a well-defined objective function for entrepreneurs, it suffices to assume that they retain a small but practically negligible fraction of net worth for their own purposes as they retire.

Production

Wholesale goods are produced according to the technology $Y_t^w = K_t^\alpha H_t^\Omega (H_t^e)^{1-\alpha-\Omega}$, where K_t denotes the aggregate capital stock, H_t denotes aggregated labor services and H_t^e denotes entrepreneurial labor services (which are assumed to be constant and normalized to one). As in Erceg, Henderson and Levin (2000), aggregated labor services are a composite of differentiated labor services provided by individual households. The problem of the household as a monopolistic supplier of differentiated labor services is discussed below. A log-linear approximation of the production function is given by

$$y_t = \alpha k_t + \Omega h_t. \quad (2.7)$$

Entrepreneurs' demand for aggregate household labor services is obtained from equating the real marginal product of labor and the real wage, W^r . In log-linear terms, this condition reads as

$$y_t - h_t + x_t = w_t^r. \quad (2.8)$$

Investment dynamics

At the end of period t , entrepreneurs purchase capital that is used for production in $t + 1$. The demand for capital is affected by two types of frictions, namely capital adjustment costs and agency problems in the credit market. Regarding the former, we assume that the aggregate capital stock evolves according to $K_{t+1} = \Phi(I_t/K_t) K_t + (1 - \delta)K_t$, where I_t represents aggregate investment and δ denotes the depreciation rate. $\Phi(\cdot)$ is an increasing and concave function capturing the presence of adjustment costs in the production of capital goods. We restrict this function so that the price of capital goods is unity in the steady state, i.e. $\Phi'(I/K) = 1$. Moreover, $\Phi(I/K) = \delta$ in the steady state, so a log-linear approximation to the law of motion for capital reads as

$$k_{t+1} = \delta i_t + (1 - \delta)k_t. \quad (2.9)$$

Conceptually, it is convenient to think of investment as being carried out in a distinct and perfectly competitive capital-producing sector owned by entrepreneurs. Here, final goods, I_t , are combined with existing capital, K_t , and transformed into new capital, K_{t+1} , under the technological constraints given by the function $\Phi(\cdot)$. The new capital is then sold to entrepreneurs at the price (in terms of the numeraire good) Q_t . We assume that investment takes time to plan, so investment expenditure is set two periods in advance. Such a time span between planning and realizing investment expenditure seems highly plausible and is suggested, *inter alia*, by Christiano and Todd (1996). As a consequence, while the asset price Q_t adjusts immediately in response to shocks, the investment response is delayed. The first-order condition that determines the investment decision of capital producers is given by $E_{t-2}Q_t = E_{t-2}[\Phi'(I_t/K_t)]^{-1}$. A log-linear approximation of this condition reads as

$$E_{t-2}q_t = \varphi E_{t-2}(i_t - k_t), \quad (2.10)$$

where $\varphi = (-\Phi''/\Phi')(I/K)$ measures the elasticity of the price of capital with respect to the investment-capital ratio. As emphasized in BGG, it is through the introduction of adjustment costs that volatile asset prices contribute to the fluctuations of entrepreneurial wealth. In addition, adjustment costs smooth out the investment response to a given shock. In the steady state, producing new capital does not yield any profits, because capital production exhibits constant returns to scale. Outside the steady state, however, profits from capital production may differ from zero, because the existing capital stock is predetermined and cannot be adjusted freely. Specifically, real profits are given by $\Pi_{E,t} = Q_t \Phi(I_t/K_t) K_t - I_t$.⁴ These profits are added to the wealth of entrepreneurs.

Financial frictions

Entrepreneurial activity is exposed to an idiosyncratic shock, $\omega_t > 0$, which has a mean of one and affects multiplicatively the total payoff from the individual entrepreneur's business. Specifically, the total payoff in period t consists of ω_t times the sum of production revenues accruing to capital and the market value of the remaining capital stock. In the aggregate, because $E\omega_t = 1$, this amounts to $\alpha X_t Y_t + (1 - \delta) Q_t K_t$.

Capital demand is determined by the expected marginal return to capital. The realized marginal return to capital is given by

$$R_t^k = (\alpha Y_t X_t / K_t + (1 - \delta) Q_t) / Q_{t-1}, \quad (2.11)$$

which implies, in log deviations,

$$r_t^k = \alpha \frac{YX}{KR^k} (y_t + x_t - k_t) + \frac{1 - \delta}{R^k} q_t - q_{t-1}. \quad (2.12)$$

To the extent that capital purchases at the end of period t , $Q_t K_{t+1}$, exceed entrepreneurial net worth, N_{t+1} , entrepreneurs depend on external finance, which is provided by a financial intermediary. This intermediary earns zero profits in equilibrium and can perfectly diversify the idiosyncratic risk associated with individual entrepreneurial projects. Opportunity costs are, therefore, given by the riskless interest rate, R_{t+1} , paid on real deposits with the intermediary from t to $t + 1$.

However, the relationship between borrowers and lenders is affected by asymmetric information with respect to the above-mentioned shock ω_t . In particular, the intermediary does not observe realizations of ω_t costlessly but faces monitoring costs equal to a fraction μ of the entrepreneur's total payoff if he wants to learn about ω_t . This assumption introduces costs of default into the model and drives a wedge between lenders' opportunity cost and the cost of credit facing entrepreneurs. BGG derive the optimal one-period loan contract that guarantees lenders a payoff that is independent of aggregate risk. The contract links repayment to a threshold value $\bar{\omega}_t$. For any realization of the idiosyncratic shock above this value,

⁴The effect of capital accumulation itself on adjustment costs is of second order and thus omitted here, see BGG.

the borrower pays the lender a fixed contractual amount, while for any realization below $\bar{\omega}_t$, the borrower defaults on his debt, so the lender audits the borrower and seizes all remaining assets net of monitoring costs. In the appendix, we detail the derivation of BGG's financial accelerator and show that the optimal contract implies an increasing relationship between the entrepreneurs' capital to net worth ratio and the premium on external funds. This relationship is the essential characteristic of the financial accelerator, since it relates financing conditions to the current balance sheet situation of borrowers. In log-linear terms,

$$E_t r_{t+1}^k - r_{t+1} = -\chi(n_{t+1} - q_t - k_{t+1}), \quad (2.13)$$

where χ measures the elasticity of financing conditions with respect to the net worth to capital ratio, see equation (A8) in the appendix. Intuitively, the more severe the agency problem between borrowers and lenders and, thus, the greater the extent of financial frictions in the economy, the higher χ will be. This parameter will therefore play a key role in the discussion below.

Lastly, entrepreneurs' wealth remains to be properly defined. At the end of period t , entrepreneurial net worth, N_{t+1} , consists of the entrepreneurial equity V_t held by the fraction ι of entrepreneurs who stay in business, the share earned by entrepreneurial labor in the production of wholesale goods, and profits resulting from the production of capital goods, $N_{t+1} = \iota V_t + (1 - \alpha - \Omega) Y_t X_t + \Pi_{E,t}$. Entrepreneurial equity, in turn, is given by

$$V_t = R_t^k Q_{t-1} K_t - R_t (Q_{t-1} K_t - N_t) - \mu \int_0^{\bar{\omega}_t} \omega R_t^k Q_{t-1} K_t f(\omega) d\omega,$$

i.e. the realized return on capital less repayment of loans. Note that the third term on the right-hand side represents the real resources devoted to monitoring entrepreneurs in default; these expenses are borne by entrepreneurs through financing conditions.

Combining the expressions for net worth and equity and log-linearizing gives the following law of motion for net worth:

$$\begin{aligned} (N/K) n_{t+1} = & \iota (\alpha Y X / K + 1 - \delta - R) (q_{t-1} + k_t) + \iota (\alpha Y X / K + 1 - \delta) r_t^k \\ & + \iota R (N/K - 1) r_t + \iota R (N/K) n_t \\ & + (1 - \alpha - \Omega) (Y X / K) y_t + (1 - \alpha - \Omega) (Y X / K) x_t + \delta q_t - \iota D \phi_t \end{aligned} \quad (2.14)$$

with $\phi_t = \log \left[\mu \int_0^{\bar{\omega}_t} \omega R_t^k Q_{t-1} K_t f(\omega) d\omega / DK \right]$ and $D = \mu \int_0^{\bar{\omega}} \omega R^k f(\omega) d\omega$.

2.2.4 Households

A generic household $z \in [0, 1]$ provides differentiated labor services, $H_t(z)$, to the entrepreneurial sector. It also decides, in period $t - 1$, over consumption $C_t(z)$ and, in principle, the wage rate $W_t(z)$ for the next period. This corresponds to the assumption of a one-period lag in the household's decision-making or, alternatively,

a conditioning on last period's information set. In addition, the household is exogenously constrained in reoptimizing its wage rate in the same way as retailers are in reoptimizing prices. However, we assume that households can insure themselves against idiosyncratic income risk resulting from the limited ability to set wages optimally in each period, see Woodford (2003). Households are, therefore, homogeneous with respect to consumption and deposits held with a financial intermediary, and the household's optimization problem can be conveniently analyzed in two stages.

Regarding consumption we adopt the internal habit specification suggested by Amato and Laubach (2004), where the degree of habit formation is indicated by $\gamma \in [0, 1]$.⁵ Specifically, at the first stage household z chooses consumption to maximize

$$E_{t-1} \left\{ \sum_{k=0}^{\infty} \beta^k \left[\frac{1}{1-\sigma} \left(\frac{C_{t+k}}{C_{t+k-1}} \right)^{1-\sigma} - \frac{1}{1+\nu} (H_{t+k}(z))^{1+\nu} \right] \right\}$$

subject to the flow budget constraint

$$\frac{W_t(z)}{P_t} H_t(z) + R_t B_t + \Pi_{H,t} \geq C_t + T_t + B_{t+1},$$

where B_t denotes real deposits held from $t-1$ to t , T_t denotes lump-sum taxes and $\Pi_{H,t}$ represents lump-sum transfers. The latter comprise profits earned by retailers and the equity of entrepreneurs who exit business. Household optimization requires that the flow budget constraint holds with equality and that the household's wealth accumulation satisfies the transversality condition. Let λ_t denote the household's marginal utility of income at date t . An approximation of the relevant first-order conditions is then given by

$$-\sigma E_{t-1} \left\{ \frac{c_t - \gamma(1-\sigma)c_{t-1}}{-\beta\gamma[(1-\sigma)c_{t+1} - (1+\gamma(1-\sigma))c_t]} \right\} = (1-\beta\gamma)E_{t-1}\lambda_t, \quad (2.15)$$

$$E_t(\lambda_{t+1} + r_{t+1}) = \lambda_t. \quad (2.16)$$

Equation (2.15) relates the marginal utility of income to lagged, current and future values of consumption, reflecting the time inseparability of utility introduced by habit formation. This condition is supplemented by the standard intertemporal optimality condition in (2.16).

At the second stage, households decide on wages. The monopolistic power of households follows from the assumption that households' specific labor services are bundled into aggregate labor services according to

$$H_t = \left[\int_0^1 H_t(z)^{\frac{\xi-1}{\xi}} dz \right]^{\frac{\xi}{\xi-1}}. \quad (2.17)$$

⁵One advantage of this ratio specification with respect to alternative (difference) specifications is that it remains well defined even if current consumption fails to exceed the habit level.

Given entrepreneurs' demand for aggregated labor services, H_t , and an optimal allocation of wage expenditure, household z faces a downward sloping demand function

$$H_t(z) = \left(\frac{W_t(z)}{W_t} \right)^{-\xi} H_t, \quad (2.18)$$

where ξ measures the wage elasticity of demand among differentiated labor services. W_t denotes the wage index

$$W_t = \left[\int_0^1 W_t(z)^{1-\xi} dz \right]^{\frac{1}{1-\xi}}. \quad (2.19)$$

Analogously to the case of retailers, a generic household can reoptimize its wage with probability $1 - \theta_w$ only. Likewise, we assume that wages which are not reoptimized in a given period are indexed to past inflation. The degree of indexation is governed by κ_w . Consequently, if the wage rate for labor services z has not been reoptimized for k periods, it amounts to $W_{t+k}(z) = W_t(z) (P_{t+k-1}/P_{t-1})^{\kappa_w}$. If instead reoptimization is possible, the household will set W_t^* set in order to maximize

$$E_{t-1} \left\{ \sum_{k=0}^{\infty} (\beta \theta_w)^k \left[\Lambda_{t+k} H_{t,t+k}(z) \frac{W_t^*}{P_{t+k}} \left(\frac{P_{t+k-1}}{P_{t-1}} \right)^{\kappa_w} - \frac{1}{1+\nu} (H_{t,t+k}(z))^{1+\nu} \right] \right\}$$

subject to the demand function (2.18). Note that $H_{t,t+k}(z)$ stands for the labor supply of household z in period $t+k$, if the most recently optimized wage came into effect in t . Further, the preference parameter ν determines the degree of disutility resulting from the provision of labor services. In the case of a Walrasian labor market, it would correspond to the inverse of the intertemporal elasticity of labor supply. The solution to the above problem satisfies the first-order condition

$$E_{t-1} \left\{ \sum_{k=0}^{\infty} (\beta \theta_w)^k H_{t,t+k}(z) \left[\Lambda_{t+k} \frac{W_t^*}{P_{t+k}} \left(\frac{P_{t+k-1}}{P_{t-1}} \right)^{\kappa_w} - \frac{\xi}{\xi-1} (H_{t,t+k}(z))^{\nu} \right] \right\} = 0.$$

A log-linear approximation of this first-order condition, together with (2.19), implies a dynamic relationship for wage inflation, $\pi_t^w = \log(W_t/W_{t-1})$, which is isomorphic to the New Keynesian Phillips Curve derived above:

$$E_{t-1} (\pi_t^w - \kappa_w \pi_{t-1}) = \beta E_{t-1} (\pi_{t+1}^w - \kappa_w \pi_t) + \lambda_w E_{t-1} (\nu h_t - \lambda_t - w_t^r), \quad (2.20)$$

where $\lambda_w = (1 - \beta \theta_w) / (\theta_w (1 + \xi \nu))$. The real wage, w_t^r , is linked to inflation and wage inflation in the following way:

$$w_t^r = w_{t-1}^r + \pi_t^w - \pi_t. \quad (2.21)$$

2.2.5 Monetary Policy

We assume that monetary policy is characterized by an interest rate feedback rule taking the following flexible form:

$$\begin{aligned} r_{t+1}^{nom} = & \rho_1 r_t^{nom} + \rho_2 r_{t-1}^{nom} + \rho_3 r_{t-2}^{nom} + \rho_4 r_{t-3}^{nom} + \\ & \phi_{\pi,1} \pi_t + \phi_{\pi,2} \pi_{t-1} + \phi_{\pi,3} \pi_{t-2} + \phi_{\pi,4} \pi_{t-3} \\ & \phi_{y,1} y_t + \phi_{y,2} y_{t-1} + \phi_{y,3} y_{t-2} + \phi_{y,4} y_{t-3} + \varepsilon_t, \end{aligned} \quad (2.22)$$

where all the coefficients are taken directly from the (constrained) VAR as in Rotemberg and Woodford (1997) and Amato and Laubach (2003). The relationship between the nominal and real interest rates is, of course, defined as

$$r_{t+1}^{nom} = r_{t+1} + E_t \{ \pi_{t+1} \}. \quad (2.23)$$

2.2.6 Market Clearing and Equilibrium

The market for final goods clears in every period,

$$Y_t = C_t + I_t + G_t + \mu \int_0^{\bar{\omega}_t} \omega R_t^k Q_{t-1} K_t f(\omega) d\omega, \quad (2.24)$$

where G_t denotes public spending.⁶ An approximation to (2.24) gives

$$y_t = (C/Y) c_t + \delta (K/Y) i_t + (DK/Y) \phi_t. \quad (2.25)$$

Likewise, financial markets clear so that deposits, B_{t+1} , meet the demand for investment finance, $Q_t K_{t+1} - N_{t+1}$.

For the purposes of our exercise, we study the equilibrium dynamics around a non-stochastic steady state. Specifically, given a shock ε_t to the interest feedback rule, we consider sequences for the following generic variables:

$$\left\{ \pi_t, \pi_t^w, r_t^k, r_t^{nom}, r_t, w_t^r, x_t, q_t, y_t, c_t, i_t, n_t, h_t, k_t, \lambda_t \right\}_{t=0}^{\infty}.$$

These variables are matched by the following equilibrium conditions: the New Keynesian Phillips Curve (2.6), the production function (2.7), the demand for labor (2.8), the law of motion for capital (2.9), investment demand (2.10), return to capital (2.12), premium on external funds (2.13), the evolution of net worth given by (2.14), the Euler equations (2.15) and (2.16), the dynamics of wage inflation (2.20), and the goods market clearing condition (2.25). In addition, we use the interest rate feedback rule (2.22) and the definitions of the real wage (2.21) and the nominal interest rate (2.23) to pin down the equilibrium.⁷ The implied system of expectational difference equations is solved numerically using the Generalized Schur Decomposition as discussed by Klein (2000). The solution of the model can be represented by a first-order autoregressive structure, which, in turn, is used to compute the impulse responses to a monetary policy shock.

⁶Government spending is included in the model in order to calibrate steady-state ratios. We assume that it is constant, i.e. $G_t = G$, and financed exclusively through lump-sum taxes.

⁷Note that the term ϕ_t in equations (2.14) and (2.25) is of second-order importance and has

2.3 Empirical Characterization of Transmission

Having introduced our theoretical model, we now turn to the empirical characterization of monetary transmission, i.e. the dynamics of output components, real wage, inflation and the interest rate *as apparent from the data*. Specifically, we use a VAR framework to obtain estimates of the empirical impulse response functions associated with a monetary policy shock. In order to ensure that the VAR actually captures the empirical equivalent of the dynamics implied by our theory, the identifying restrictions we use in our VAR have to be consistent with the model. This requires that the timing of dynamic responses in the VAR be no more restrictive than in the model. Consequently, monetary policy shocks are identified by assuming that inflation, real wage, output and its components do not respond contemporaneously to a shock in monetary policy. This is a standard assumption in the empirical literature and can easily be justified from planning and implementation lags such as those incorporated into our model. Likewise, we follow standard practice and allow for four lags in the VAR. The structure of the interest rate feedback rule (2.22) is imposed in the estimation, since we directly import this rule from the VAR into the model.

Another important note concerns the remaining variables we include in our VAR. The guiding principle here again is correspondence with the theoretical model, taking into account the canon of previous empirical work. Apart from the variables usually considered as the minimum specification, i.e. output (y), inflation (π) and the federal funds rate (r^{nom}), we also include the real wage (w^r) as well as the components of output, consumption (c) and investment (i), whose responses we are particularly interested in. Since, in the theoretical model, the dynamics of these variables are driven by the state variables, notably capital and net worth, it seems appropriate to proxy for these variables in the empirical model, as well. We therefore include the inverse of the interest coverage ratio as a proxy variable that captures changes in the financial situation of corporate borrowers. The variable, which we also dub "corporate interest burden" (cib) is defined as the ratio of net corporate interest expenditure to pre-tax profits plus interest expenditure. It has been suggested by previous authors in the literature on financial frictions, e.g. Bernanke and Gertler (1995), as a good real-time measure of financial strain in the corporate sector, thus proxying directly for the net-worth channel we would like to examine. Realistically, we allow this variable to respond contemporaneously to changes in nominal interest rates.⁸

no perceptible impact on the dynamic behavior of the economy. The reason already pointed out by BGG is that, in the log-linearized equations, this term is weighted by the steady-state level of monitoring costs relative to the steady-state values of equity and output, respectively. Even for the highest values of χ that we consider, the weight of this term does not exceed 0.13 percent in the equity equation and 0.5 percent in the output equation. Therefore we ignore the term in the numerical simulations below.

⁸Finding satisfactory proxies for the capital stock is more difficult, which explains the common practice of specifying empirical VARs without capital. The potential pitfalls of this practice have recently been highlighted by Chari, Kehoe and McGrattan (2005). In contrast, Altig et al. (2005)

Our VAR thus comprises the seven variables (the first two pertaining to period t , the rest to $t + 1$) contained in

$$Z_t = (r_{t+1}^{nom}, cib_t, w_{t+1}^r, \pi_{t+1}, y_{t+1}, i_{t+1}, c_{t+1})'$$

and takes the following form:

$$T\bar{Z}_t = m + A\bar{Z}_{t-1} + \bar{\epsilon}_t, \quad (2.26)$$

where $\bar{Z}_t = (Z_t', Z_{t-1}', Z_{t-2}', Z_{t-3}')'$, T is a 28×28 identity matrix with a lower triangular 7×7 matrix in the upper left corner that contains the coefficients capturing the contemporaneous relationships between the variables in Z_t . m is a vector of 28 constants. The 28×28 matrix A contains coefficients in the first seven rows only, since the other rows impose identities. As a consequence, only the first seven elements of the vector $\bar{\epsilon}_t$ are different from zero, representing structural shocks. Moreover, since the first row of A contains the coefficients of the interest rate reaction function, which is also used in the theoretical model, we restrict the coefficients on all variables except inflation, GDP and lagged interest rates to be zero. Hence, under this identification scheme, the first element of the vector $\bar{\epsilon}_t$ may be interpreted as a monetary policy shock, ε_t . The structure of (2.26) is very similar to the one considered by Rotemberg and Woodford (1997) and Amato and Laubach (2003), but allows for even more general dynamics following a monetary policy shock. We estimate this VAR recursively by OLS.

The data we use are quarterly US data taken from the NIPA of the BEA (real GDP, real consumption, real investment, real hourly compensation in nonfarm business sector, GDP deflator, corporate profits and net interest payments) and the Board of Governors of the Federal Reserve System (federal funds rate). The data are transformed in the following way: In accordance with the model, y , i , c and w^r are defined as log deviations from constant steady-state growth. Our measure of financial tightness, cib , is a detrended ratio variable, while inflation π is computed from log differences of the GDP deflator. Finally, the federal funds rate, r^{nom} , is divided by 400 to obtain a measure for the quarterly interest rate.⁹

The sample we consider is 1980:1 through 2003:4, covering essentially the entire Volcker-Greenspan period to date. Because we wish to identify the historical monetary rule from the VAR, it is important to estimate it over a sample period in which the coefficients of (2.22) can reasonably be assumed to be constant. According to several authors, including Boivin and Giannoni (2003), policy since the Volcker disinflation of the early 1980s has indeed displayed a high degree of stability.

document that for reasonably large VAR specifications, the omission of capital is not very problematic. For the purposes of our own study, we also conducted a small-scale Monte Carlo experiment. Our results (available upon request) strongly confirm the conclusion drawn by Altig et al.

⁹Note that output and the other level series do not need to be divided by four, since they only show up as log deviations from steady state, i.e. in percentage terms. In contrast, shocks to the interest rate are in terms of percentage points. Inflation is already measured and expressed at quarterly frequency.

Turning to the results of our VAR estimation, we begin with the characterization of monetary policy based on estimates from the first equation. As is well-known, the long-run response of the central bank to changes in inflation is an important determinant for the stability of the economy. Our estimates indicate that the FED's policy has satisfied the so-called Taylor Principle in the Volcker-Greenspan period. Specifically, the coefficients on inflation add up to 0.4766, while those on the lagged interest rate sum to 0.7853, implying a long-run response of 2.22, greater than one. This finding corresponds closely with the results reported in Clarida, Galí and Gertler (2000).

Next, we use the estimated VAR to obtain an empirical characterization of the transmission of a monetary policy shock ε_t . The impulse responses of all seven variables are depicted in figure 1. Note that impulses are measured in terms of percentage deviations (percentage point deviations in the case of inflation, corporate interest burden and the interest rate) from the unshocked path, following a unit shock in the quarterly federal funds rate. The shaded areas give 90 percent confidence bands, computed by bootstrapping based on 10,000 replications.¹⁰

The responses of our key variables, output, consumption and investment, show the familiar pattern, i.e. a roughly hump-shaped decline with peak responses after two to five quarters. All of these responses are significant, although the reaction of investment is much larger in percentage terms than the consumption response. Furthermore, we observe a slight but protracted decrease in inflation as well as a significant fall in the real wage. The interest rate declines for roughly one year before it reaches its steady-state level again. Lastly, our "corporate interest burden" variable shows a marked increase following the contractionary monetary shock. This squares well with the intuition that higher interest rates will lead to tighter financial conditions in the corporate sector, even though the relative importance of financial frictions for this result cannot be immediately inferred. Overall, our findings are in line with the stylized facts reported by, for example, Christiano, Eichenbaum and Evans (1999). In the following they will be confronted with the predictions of our theoretical model.

2.4 Estimation Strategy

Having characterized our data and model, we are now in a position to match empirical (VAR) and theoretical (DSGE) impulse responses, thereby obtaining estimates for the structural parameters of our model. Rotemberg and Woodford (1997) were the first to suggest this estimation technique in the context of DSGE models.¹¹ Similar approaches have subsequently been applied by Amato and Laubach (2003), Boivin and Giannoni (2003), Giannoni and Woodford (2003) and CEE.

¹⁰The bootstrap is also used to compute the covariance matrix of the impulse responses that we require for the main estimation exercise, as discussed in the next section.

¹¹Note the early use of a similar statistic, merely for specification testing, in Cogley and Nason (1994).

Generally, one important question in minimum distance estimation concerns the issue of which moments or auxiliary statistics to match. From an econometric point of view, the moments used in estimation should be as informative as possible, in the sense of bearing strong and distinct relationships with each of the structural parameters. While it is often difficult to evaluate this property in a stringent way, Adda and Cooper (2003) note that the selection of moments may also be guided by other criteria. Economic interest, indeed, would suggest considering aspects of the data that are important in their own right, e.g. because they shed light on the merits of an important theory or because they matter most for economic policy. Against this background, we consider, as the relevant feature to match, the VAR impulse responses characterizing monetary transmission in the data. Importantly, in doing so we concentrate on the propagation of one particular shock only, i.e. a shock to monetary policy, remaining agnostic about the complete specification of the data generating process. In our view, this limited-information strategy fits the stylized character of modern macroeconomic models, although it is certainly less ambitious (or trustful of the descriptive value of these models) than full-fledged maximum likelihood estimation.

Formally, define Ψ_T^e to be the *empirical* impulse response function characterizing our data set of length T . Note that Ψ_T^e is not a raw moment but a transformation of the estimates obtained from a VAR which is supposed to capture the empirical counterpart of the dynamics described by our log-linearized model. The model itself, in turn, assigns to each admissible vector of structural parameters θ a theoretical impulse response function $\Psi^t = \Psi(\theta)$. The binding function $\Psi(\cdot)$ must be assumed to be injective to ensure identification. Thus we obtain an estimate for the parameter vector of interest, $\hat{\theta}$, by minimizing the weighted distance between empirical and theoretical impulse response functions, i.e. Ψ_T^e and Ψ^t :

$$\hat{\theta} = \arg \min_{\theta \in \Theta} (\Psi_T^e - \Psi(\theta))' W_T (\Psi_T^e - \Psi(\theta)), \quad (2.27)$$

where W_T represents a positive definite weighting matrix, with $W = \text{plim} W_T$ also being positive definite. Our choice of W_T is discussed below.

As there is no analytical expression for the relationship between structural parameters and impulse response functions, we rely on numerical methods to obtain a solution for (2.27). Note, in this context, that our estimation exercise does not share the problem of many other simulation-based estimation techniques, in which repeated simulations have to be made to determine Ψ^t for a given θ . The reason already discussed above is that we focus on the economy's deterministic response to one well-defined shock, abstracting from all other sources of stochastic variation present in the data. Likewise, our estimation problem is somewhat different from typical applications of the so-called Method of Simulated Moments (MSM), where the equivalent of a theoretically derived moment condition can be computed for each of T (or i) observations in the sample. Instead, we basically have no more than one observation of the auxiliary statistic of interest, Ψ_T^e . Therefore we establish the statistical properties of Ψ_T^e by means of bootstrapping, prior to the actual minimum

distance estimation.

Define Σ as the asymptotic covariance¹² of $\sqrt{T}(\Psi_T^e - \Psi)$, and let $\widehat{Avar}(\Psi_T^e)$ denote our bootstrap estimate for the asymptotic variance of Ψ_T^e , so that $\widehat{Avar}(\Psi_T^e) = \widehat{\Sigma}/T$. Then, in order to obtain efficient estimates,¹³ we can choose W_T to be the optimal weighting matrix W^{opt} , i.e. the inverse of our estimate of Σ :

$$W^{opt} = (\widehat{\Sigma})^{-1} = [T\widehat{Avar}(\Psi_T^e)]^{-1}. \quad (2.28)$$

Although several other authors have acknowledged the possibility and promise of using this weighting matrix, we are not aware of any application. Boivin and Giannoni (2003), for instance, point at difficulties with their minimization algorithm. Clearly, estimating large covariance matrices may pose problems in practice, but throughout our exercises we have not encountered any obstacles that would preclude their use. One alternative weighting matrix that was chosen by several other authors is a diagonal matrix, W^{diag} , whose inverse has the same diagonal entries as the inverse of W^{opt} , while all off-diagonals are set to zero. In other words, W^{diag} is a matrix that has, on its diagonal, the reciprocal values of the asymptotic variance of the impulse responses. Using this weighting matrix amounts to embracing an optical criterion in that the theoretical impulse responses are made to be as close to the empirical ones as possible, in terms of point-wise standard deviations. Despite its appeal, this is perhaps not the most convincing criterion, insofar as it completely ignores the probabilistic relationship between different impulse responses. In particular, as Dedola and Neri (2004) remark, a diagonal weighting matrix treats deviations from the point estimates as independent, while in fact they show substantial correlation. This observation is related to a similar point raised by Sims and Zha (1999), who note that the standard one-deviation error bands considered point-wise do "not directly give much information about the forms of deviation from the point estimate of the response function that are most likely." Below, we will report estimates for both choices of W_T .

One further choice concerns the length of the series to be considered. We match impulse responses for output, consumption, investment, real wage, inflation and the interest rate over the first twelve quarters following the impact. These are all six series for which there is a clear correspondence between the model and the VAR. Moreover, three years appear to be a reasonable period in order to gauge the effects of a one-time nominal shock. Indeed, most economists would agree (and our VAR results suggest) that real variables should largely return to their steady-state values within that time.¹⁴

Invoking the arguments in McFadden and Newey (1994), we will rely on the

¹²We follow previous authors in this literature and implicitly rule out cases where the asymptotic covariance would be degenerate. For a discussion, see Benkowitz, Lütkepohl and Neumann (2000).

¹³Of course, efficiency here refers to a given choice of an auxiliary statistic to match.

¹⁴Still, to check for the robustness of our findings, we also report estimates based on matching, respectively, eight and sixteen periods after the impact. See table 2 below.

following expression for the asymptotic variance of our estimator.

$$\sqrt{T}(\hat{\theta} - \theta) \rightarrow^d N\left(0, (G'WG)^{-1} (G'W\Sigma W'G) (G'WG)^{-1}\right), \quad (2.29)$$

which, in the case of using the optimal weighting matrix, simplifies to

$$\sqrt{T}(\hat{\theta} - \theta) \rightarrow^d N\left(0, (G'\Sigma^{-1}G)^{-1}\right), \quad (2.30)$$

where $G = \nabla_{\theta}\Psi^t$ denotes the Jacobian of the impulse response function generated from the model. All matrices contained in (2.29) and (2.30) can be estimated consistently. Specifically, estimates of W and Σ are obtained as by-products of our bootstrapping procedure, and G can be obtained from numerical differentiation. Thus, the asymptotic variance of $\hat{\theta}$ reads as

$$\widehat{Avar}(\hat{\theta}) = \left(\hat{G}'W_T\hat{G}\right)^{-1} \left(\hat{G}'W_T\widehat{Avar}(\Psi_T^e)W_T\hat{G}\right) \left(\hat{G}'W_T\hat{G}\right)^{-1}, \quad (2.31)$$

or, for $W = W^{opt}$,

$$\widehat{Avar}(\hat{\theta}) = \left(\hat{G}'\left(\widehat{Avar}(\Psi_T^e)\right)^{-1}\hat{G}\right)^{-1}, \quad (2.32)$$

allowing us to report asymptotic standard errors for our estimates.

2.5 Results

2.5.1 Parametric Setup

We partition the parameters of our structural model in three groups. The first group comprises parameters that can be fixed before the actual estimation exercise, because their values are inferable from first moments of the data or otherwise uncontroversial. Specifically, we set the time discount rate, β , to 0.99, while the quarterly capital depreciation rate, δ , is fixed at the usual 2.5 %. The output shares of household labor, Ω , and capital, α , take the standard values of 64 % and 35 %, respectively. The remaining 1 % accrue to entrepreneurs' labor in our model. The elasticity of substitution among alternative differentiated goods, ϵ , is set to eight. This is close to the value reported by Rotemberg and Woodford (1997) and implies a plausible steady-state markup of approximately 15 percent. Lastly, in terms of output components, we fix the share of government spending at 20 %, the long-run average in the data. Note that the remaining steady-state values, i.e. of capital, output, net worth and consumption are updated for each parameter configuration, to be consistent with the micro structure of the model economy. In fact, these levels are functions of the primitives of the contracting problem that is at the root of the financial accelerator. However, these primitives are not separately identified - only the "reduced form" elasticity of financing costs with respect to net worth is, and

it is one of the parameters we are estimating (χ). Thus we explicitly make steady-state values a function of χ , where the exact functional relationship is based on an assumed variation of two of the deep parameters, leaving the third one fixed.¹⁵

The second group of parameters are those characterizing monetary policy. As detailed before, we specify a fairly general interest rate feedback rule, whose coefficients are estimated as a by-product of our VAR. These estimates are directly fed into our structural model, so as to ensure consistent definitions of the monetary policy rules in the model and the VAR.¹⁶

Finally, we are left with the group of parameters we would like to estimate. The vector comprises nine coefficients, i.e. $(\lambda_p, \kappa_p, \lambda_w, \kappa_w, \chi, \varphi, \sigma, \gamma, \nu)$. However, we decide to drop the inverse of the intertemporal elasticity of labor supply, ν , from that list to reduce the dimensionality of our estimation exercise and reflecting concerns that this parameter is poorly identified.¹⁷ In our baseline setup, we consider $\nu = 3$. This value conforms with the predominant evidence, from microeconomic studies, of relatively low labor supply elasticities, see the discussion in Pistaferri (2003). Note further that we cannot identify the Calvo parameter θ_w individually, given that it only appears jointly with the demand elasticity ξ . Thus, we simply report the slope parameter λ_w from the wage inflation equation (2.20). From this value, consistent combinations of θ_w and ξ can be computed. For comparability, we proceed symmetrically with respect to the slope parameter λ_p from the Phillips curve equation (2.6); without strategic complementarities in retailers' production, the Calvo parameter θ_p can actually be inferred from λ_p . Recall next, that κ_p and κ_w are the indexation parameters from equations (2.6) and (2.20); χ is the elasticity of financing costs with respect to borrowers' net worth (equation (2.13)); φ denotes the elasticity of the price of capital with respect to the investment-capital ratio (equation (2.10)); σ is the preference parameter from our power utility function; and, lastly, γ represents the habit formation term from equation (??). In accordance with theory, κ_p , κ_w and γ are constrained to be between 0 and 1; λ_p , λ_w must be positive, σ greater than one and χ and φ non-negative.

2.5.2 Point Estimates

Table 1 provides the results of our baseline estimation exercise. We estimate on the basis of (2.27), once using efficient weighting, W^{opt} , and once the simpler diagonal weighting matrix, W^{diag} , that has been used exclusively in the previous literature. Standard errors are in parentheses, except for parameters that were estimated to be on a bound. Although confidence intervals are relatively wide for certain parameters,

¹⁵See appendix A.3 for a detailed exposition.

¹⁶Note that we refrain from treating the Taylor rule coefficients as "generated regressors". Basically, they are regarded here as given, as would be done in standard calibration or simulation exercises.

¹⁷Apart from our own evidence on this point, this is also the finding of several independent studies using different estimation methods, e.g. Dedola and Neri (2004). Table 2 below reports robustness checks for the case where we set ν to 1 (unit elasticity) and 5, respectively. The most noticeable effect of variation in ν is on estimates of λ_w , as suggested by equation (2.20).

our estimates generally have sufficient precision to judge the relative importance of different model features. Indeed, some parameters are pinned down quite precisely, especially using the efficient weighting matrix. Furthermore, all estimates lie in a reasonable range.

Consider first the results for the 'efficient weights' estimation in column 3. Nominal rigidities in price setting appear to be very pronounced, as can be inferred from the low coefficient we find for λ_p . Even taking standard errors into account, this estimate indicates significant sluggishness in prices. The point estimate for λ_w is considerably larger and less precisely estimated, suggesting weaker, if still important, rigidities in wage setting. Remember that low estimates for λ_p and λ_w are consistent with high values of the Calvo parameters θ_p and θ_w and/or a high value of the demand elasticity ξ , in effect implying markedly flat Phillips and wage inflation curves.¹⁸ Our results thus align with the findings reported by Giannoni and Woodford (2003) and suggest a strong role for nominal rigidities, especially in prices. In addition, the optimal parameter vector implies full indexation of both labor and goods contracts, since both κ_p and κ_w are estimated to be equal to the upper bound of one. This again confirms earlier findings by Giannoni and Woodford (2003) as well as Boivin and Giannoni (2003). Next, the coefficient associated with capital adjustment costs, φ , is estimated to be highly significant at 0.6464. The point estimate implies that a one percent increase in the investment-capital ratio raises the price of capital by roughly 0.65 percent, a high but plausible number. Likewise, our estimate of σ falls into the usual range: in the absence of habit formation, a power utility coefficient of 3.64 would imply an intertemporal elasticity of substitution of 0.27. Interestingly, habit formation actually appears to be very mild, with γ estimated insignificantly at 0.1206. This is in contrast with results found by Giannoni and coauthors and casts doubt on the claim that habit formation is essential to obtain a sufficient match between theory and data. Finally, our main parameter of interest, χ , is estimated at sizeable 0.0672, implying that a one percent decrease in the net worth to capital ratio raises the cost of external finance by almost 7 basis points per quarter. While this value is a little higher than the number assumed in BGG's simulations, our estimate is not statistically significant, with a t-statistic of 1.48. Accordingly, it is not quite clear yet what is the quantitative importance of financial frictions for obtaining a good match between our theoretical model and the data.

Column 4 of table 1 reproduces the corresponding results for the estimation using the simple diagonal weighting matrix. As mentioned above, the main difference from the case of efficient weighting is that now estimates are chosen so as to minimize the simple sum of point-wise distances between empirical and theoretical impulse responses, in terms of standard deviations. While greater weight is, thus, given

¹⁸To the extent that very strong nominal rigidities seem to be at odds with microeconomic evidence on price setting, our results highlight the importance of finding additional model features that reduce the pass-through of prices into marginal costs. Along these lines, for instance, Eichenbaum and Fisher (2004) consider firm-specific capital in the retail sector combined with a non-constant elasticity of substitution among differentiated goods. Thus even low macroeconomic estimates of λ_p can be reconciled with plausible values of θ_p .

to more precisely estimated impulse responses, the estimation does not take into account any correlation between different points of the impulse response functions. Overall, the estimates are relatively close to the ones discussed above, although standard errors are considerably larger. Nominal rigidities in prices are again estimated to be strong, with λ_p taking a very low value. The new estimate for λ_w is also in the same ballpark as the value in column 3. Next, estimates for κ_p and κ_w confirm our previous findings on the indexation of contracts, even though κ_p is now estimated just below its upper bound of one but significantly different from zero. The estimate for φ is somewhat lower than before, whereas σ and γ are estimated to be slightly higher. Lastly, our central parameter of interest, χ , is estimated at 0.0616, very close to the previous estimate but far from significant.

Taken together, the results suggest that sensible parameter estimates can be obtained from our estimation exercise. Specifically, explaining the impulse responses to a monetary policy shock appears to require strong nominal rigidities, especially in prices. In addition, we find evidence for (nearly) full indexation of contracts and sizeable capital adjustment costs. At the same time, our estimation lends only mild support for the presence of financial accelerator effects. Furthermore, habit formation does not seem to have a role to play in bringing our model in line with the data.

In some cases, however, standard errors are relatively large. Moreover, the exact shape of the criterion function is unknown, suggesting that further tests should be conducted to draw firm conclusions about the relevance of all features encompassed by our model. Before tackling this issue, we reproduce, in figure 2, the impulse responses implied by the structural parameter estimates given in table 1. As can be seen from the graph, the empirical impulse responses are tracked quite well by the model evaluated at our parameter estimates. Both the magnitude and the persistence of the impulse responses generated by the VAR are replicated, and the model-based responses remain consistently within the confidence bands. Not surprisingly, the better graphical fit is obtained by the parameter vector from the last column of table 1. This follows immediately from the criterion function and may explain in part why other authors using minimum distance methods have tended to opt for a diagonal weighting scheme. Note, however, that optical fit is not necessarily the most convincing criterion in that it fails to take into account the full probabilistic pattern of impulse responses.

2.5.3 The Impact of Parameter Perturbations

To get some additional insight into the effects of some features of the model, consider two perturbations from our estimated parameter vector as reported in the last column of table 1. First, in figure 3, we set the value of χ to zero, corresponding to the case without financial frictions. All other parameters remain at their estimated values for this exercise. In comparison with the baseline picture, the most striking changes are visible from the responses of investment and, somewhat less, output and the real wage. Given that financial frictions tend to reinforce fluctuations in

investment, the investment response is now considerably weaker. Without financial frictions, investment falls by nearly half of the decline observed previously in figure 2. At the same time, consumption shows only a mild change in the opposite direction, highlighting the interest of looking at individual output components. Indeed, if consumption and investment were not taken into account individually, the parameter configuration underlying figure 3 would look very sound, given the good fit with the empirical *output* series. However, empirical investment differs substantially from the theoretical impulse responses. The incremental information provided by the component series can thus be very valuable in judging features of the model which, like the financial accelerator, imply distinct compositional effects.

Another variation from our estimated values is analyzed in figure 4. There, we set the habit parameter γ to its upper-bound value of one. As suggested by the notion of habit formation, consumption now drops much less in response to the initial shock but smooths out the adjustment in a protracted decline. Other series are not affected very much.

Similar perturbation exercises can be made for all other features of the model. Our general impression is that the impulse responses are quite informative about the parameters we seek to estimate, since even small changes tend to have clear effects on the shape of different impulse response series. For instance, variation in the slope parameter λ_p has a considerable impact on all impulse responses, especially inflation and the real wage. Similarly, λ_w and the indexation parameter κ_p have a clear bearing on the shape and magnitude of the inflation and real wage responses, whereas the effects of varying κ_p are more limited. Investment, in turn, is strongly affected by φ : the higher this parameter, the lower and more protracted the fall in investment. Likewise, higher values of σ naturally dampen the consumption response. Clearly these findings are good news for our empirical endeavor to identify the parameters of the model. They also suggest that, if the estimates in table 1 are sometimes not very precise, this is not because the model's parameters do not affect the economy's response to a monetary shock. Rather, the likely reason is that the model is fairly flexible and thus provides at least a decent fit with the data for a range of different parameter configurations. Whether or not at least some features of the model are indispensable for its empirical success will be addressed in the next section. First, it should be pointed out that the results obtained for our baseline estimation are nicely confirmed by a number of robustness checks reported in table 2. We consider the case where estimation, always using efficient weights, is based on matching shorter (eight quarters) and longer (sixteen quarters) series of impulse responses than in our baseline case (twelve quarters). In addition, we report estimates for different values of the preset labor supply parameter ν .

2.5.4 Distance Metric Tests

The central question we wish to address in this paper refers to the quantitative importance of various model ingredients. In fact, our model nests a number of interesting special cases, such as strong habit formation or the absence of financial

frictions. In order to judge the severity of these and other restrictions, a first informative statistic is provided by the standard errors in tables 1 and 2. However, given the unknown, possibly irregular shape of the criterion function, we prefer to rely on additional evidence. We therefore propose to use a distance metric test of specific model restrictions as presented in Wooldridge (2002, ch. 14.6). In spirit the test is very close to a likelihood-ratio test. Specifically, we compute the loss functions (using efficient weighting, which is now essential for the validity of the approach) for restricted models in which one parameter is pre-fixed at a given value of interest and all other parameters are estimated. Intuitively, if the loss functions differ greatly between the restricted and the unrestricted model, we can reject the null that the parameter takes on the assumed value. The test statistic in our case looks as follows:

$$(L_r^* - L_u^*) \sim^a \chi^2 (\# \text{ restrictions})$$

and is asymptotically distributed as Chi-squared with degrees of freedom equal to the number of restrictions imposed. L^* denotes the value of the loss function at its optimum, i.e.

$$\begin{aligned} L^* &= \min T(\Psi_T^e - \Psi(\theta))' \widehat{\Sigma}^{-1} (\Psi_T^e - \Psi(\theta)) \\ &= \min (\Psi_T^e - \Psi(\theta))' \left(\widehat{Avar}(\Psi_T^e) \right)^{-1} (\Psi_T^e - \Psi(\theta)), \end{aligned}$$

and indices r and u stand for the restricted and unrestricted minimization problem, respectively.

To begin with, we revisit the finding that the habit parameter, γ , was consistently estimated to be close to its lower bound of zero, suggesting a minor role for habit formation. We reestimate our structural parameter vector, now forcing γ to zero. The results of this restricted estimation exercise are provided in table 3, along with several further cases. Although the optimum loss function value is slightly higher than in the unrestricted case, the difference is clearly too small to reject the null hypothesis. Note that this conclusion aligns well with the evidence already provided by the standard errors in tables 1 and 2.

Considering, next, the restriction of $\gamma = 1$, we observe a markedly different result. Imposing strong habit formation causes the model a substantial loss of fit with respect to the unrestricted model. Accordingly, we can reject this null hypothesis at any conventional level (p-value 0.0003). The main reason for the descriptive inaptitude of the restricted model appears to be the distinct impact of habit formation on the consumption response that was already visible from figure 4. Even when other parameters are allowed to adjust, the dampening of the initial consumption response goes counter to what the VAR impulse responses show. It would thus seem that our model admits a moderate extent of internal habit formation at most in order to match the empirical evidence.

Apart from preference parameters, other hypotheses of obvious interest concern the real frictions embedded in the most general model. Thus, we next examine the loss in descriptive quality of our model when capital adjustment costs are assumed to

be absent. As the results in column 4 indicate, this restriction is forcefully rejected by the data. Indeed, the minimum loss deteriorates substantially - to more than six times the loss of the best unrestricted model. At the same time, the remaining parameter estimates take quite extreme values. Real frictions in the investment process thus appear to be critical for the descriptive success of the model, notably to generate the protracted decrease in investment. While this result is not very surprising, a less predictable observation can be made regarding the specific type of financial frictions we have embedded into our model. Given the inconclusive evidence regarding the quantitative importance of financial frictions from our previous estimates, we formally test the restriction of no financial accelerator effects. More precisely, in our last experiment we set χ to zero and re-estimate all other parameters of the model. The results in column 5 indicate that this restriction cannot be formally rejected. Although financial frictions improve the model's fit with the data, they do not do so strongly enough to produce significant support for $\chi > 0$. In terms of point estimates, the main consequence of fixing χ at zero is a decrease in the capital adjustment parameter, φ , along with a further decrease in λ_p and a higher estimate of σ . As it turns out, the absence of financial frictions can be comfortably offset by somewhat weaker capital adjustment costs, while the opposite is not true. In this sense, the quantitative importance of financial frictions is relatively limited.

A nice feature throughout is that our distance metric tests fully confirm the results from simpler Wald-type tests based on point estimates and the associated standard errors. In small samples, this equivalence need not necessarily hold, so we have reason to feel all the more reassured about our conclusions as to the relative importance of the different model components we have studied.

2.6 Conclusion

One of the ongoing challenges in the macroeconomic literature, according to Woodford (2003), is to develop a "fully realistic quantitative model of the monetary transmission mechanism". We try to contribute to this research agenda by evaluating the relative importance of different features encompassed by a candidate model. The idea is to find out which aspects of the real and the nominal side of a New Keynesian model are crucial to account for the stylized facts of monetary transmission, as summarized by a typical set of empirical impulse response functions. In particular, we wish to evaluate the importance of financial frictions. To this purpose, we propose a model which embeds Bernanke, Gertler and Gilchrist's (1999) financial accelerator into a medium-scale DSGE framework. In order to obtain estimates for the structural parameters of our model, we use a minimum distance strategy that matches the impulse responses implied by the model with those estimated from US data for the Volcker-Greenspan period. Particular emphasis is given to explaining not only the response of aggregate output but also the individual behavior of consumption and investment. Moreover, we explicitly take correlation between different impulse responses into account by using an efficient weighting scheme in our minimization.

This procedure also lends itself nicely to an insightful evaluation, through distance metric tests, of individual features that are nested in the most general model.

Our model, evaluated at the parameter estimates, is able to reproduce quite well the shape and magnitude of the empirical impulse responses. For this to be the case, the model requires strong nominal rigidities in prices and slightly less so in wages. There is also evidence for a significant degree of price indexation and against strong habit formation in consumption. In addition, our results ascribe an important role to capital adjustment costs - apparently an indispensable feature on the real side of our New Keynesian model. In contrast, the financial accelerator seems less important than we would have conjectured. Although we obtain sizeable point estimates for the relevant parameter, they fail to be statistically significant. The same conclusion is suggested by our distance metric tests, which show financial frictions to have only a marginal impact on improving the model's fit with the data.

In a sense, this finding may lend support to the widespread use of DSGE models that refrain from incorporating financial accelerator effects. An obvious caveat is that we focus on the propagation of one shock only, singling out monetary transmission as the relevant benchmark of empirical success. It is, therefore, conceivable that financial frictions have a more crucial role to play as the model is confronted with additional aspects of the data. Similarly, one could consider an extended version of the baseline financial accelerator model that allows for heterogeneity across sectors. Gertler and Gilchrist (1994), for instance, report that small firms contract substantially relative to large firms after a monetary tightening, so the assumption of homogeneous responses across firms may be overly restrictive. We think our framework is well suited to address these issues in future research.

2.7 Appendix

In this appendix, we sketch the microfoundations of the financial accelerator model borrowed from BGG. Its core element is a problem of costly state verification between borrowers and lenders, giving rise to an external finance premium that is inversely related to borrowers' net worth positions. The following draws on a shorter exposition of the problem contained in Gertler, Gilchrist and Natalucci (2003).

A. Debt Contract

To illustrate the contracting problem between borrowers and lenders, we provide an analysis for the steady state, where aggregate risk is absent. Let N denote the steady-state level of net worth, Q the price of capital (equal to one in steady state) and K the steady-state level of the capital stock. The entrepreneur borrows $QK - N$ to invest K units of capital in a project. Furthermore, let R^k denote the aggregate steady-state return on capital. The return on the project of an individual entrepreneur is ωR^k , where ω represents a multiplicative lognormal shock with mean one, i.e. $\ln(\omega) \sim N(-\frac{1}{2}\sigma_\omega^2, \sigma_\omega^2)$. For a given realization of the idiosyncratic shock ω , the total payoff on the entrepreneur's capital is thus $\omega R^k QK$. Note that ω is

unknown to both the entrepreneur and the lender prior to the investment decision. Even after the realization of the idiosyncratic shock, the lender can only observe ω by paying a proportionate monitoring cost, $\mu\omega R^k QK$. Lenders are assumed to be (competitive) financial intermediaries who earn zero profits in equilibrium and are able to perfectly diversify idiosyncratic credit risk. Accordingly, their opportunity cost is R , the riskless interest rate.

Given this setup, the optimal one-period loan contract that leaves lenders without any aggregate credit risk can be shown to specify a threshold value $\bar{\omega}$ for the idiosyncratic shock such that if $\omega \geq \bar{\omega}$, the borrower pays the lender the fixed amount $\bar{\omega} R^k QK$ and keeps the equity $(\omega - \bar{\omega}) R^k QK$. Alternatively, if $\omega < \bar{\omega}$, the borrower declares bankruptcy, the lender monitors the borrower and receives $(1 - \mu)\omega R^k QK$ in residual claims net of monitoring costs. In equilibrium, loan contracts must satisfy the condition that the intermediary earn his opportunity costs, i.e.

$$\left((1 - \mu) \int_0^{\bar{\omega}} \omega f(\omega) d\omega + \bar{\omega} \int_{\bar{\omega}}^{\infty} f(\omega) d\omega \right) R^k QK = R(QK - N). \quad (A1)$$

The optimal contract maximizes the payoff to the entrepreneur subject to (A1). Given constant returns to scale, the threshold value $\bar{\omega}$ determines the division of expected gross payoff, $R^k QK$, between borrower and lender. Let $\Gamma(\bar{\omega}) = \int_0^{\bar{\omega}} \omega f(\omega) d\omega + \bar{\omega} \int_{\bar{\omega}}^{\infty} f(\omega) d\omega$ denote the gross share of the payoff going to the lender, while $\mu G(\bar{\omega}) = \mu \int_0^{\bar{\omega}} \omega f(\omega) d\omega$ denotes the expected share pertaining to monitoring costs. The payoff share going to the entrepreneur is thus given by $1 - \Gamma(\bar{\omega})$. Defining $k = QK/N$ and $s = R^k/R$, we can set up the Lagrangian for the problem

$$L = (1 - \Gamma(\bar{\omega})) sk + \lambda [(\Gamma(\bar{\omega}) - \mu G(\bar{\omega})) sk - (k - 1)].$$

The following optimality conditions are obtained:

$$\begin{aligned} \frac{\partial L}{\partial \bar{\omega}} &: \Gamma'(\bar{\omega}) - \lambda (\Gamma'(\bar{\omega}) - \mu G'(\bar{\omega})) = 0, \\ \frac{\partial L}{\partial k} &: \Upsilon(\bar{\omega}) s - \lambda = 0, \\ \frac{\partial L}{\partial \lambda} &: (\Gamma(\bar{\omega}) - \mu G(\bar{\omega})) sk - (k - 1) = 0, \end{aligned}$$

where $\Upsilon(\bar{\omega}) \equiv 1 - \Gamma(\bar{\omega}) + \lambda(\Gamma(\bar{\omega}) - \mu G(\bar{\omega}))$. Rearranging gives

$$s(\bar{\omega}) = \frac{\lambda}{\Upsilon(\bar{\omega})} \quad (A2)$$

and

$$k(\bar{\omega}) = \frac{\Upsilon(\bar{\omega})}{1 - \Gamma(\bar{\omega})}, \quad (A3)$$

where the Lagrange multiplier, λ , is now also defined as a function of $\bar{\omega}$, by virtue of the first optimality condition noted above: $\lambda(\bar{\omega}) = \Gamma'(\bar{\omega}) / (\Gamma'(\bar{\omega}) - \mu G'(\bar{\omega}))$. BGG show that both $s'(\bar{\omega}) > 0$ and $k'(\bar{\omega}) > 0$. This ensures the existence of a relationship

$$k = \psi(s), \text{ with } \psi'(s) > 0 \quad (A4)$$

that links the external finance premium, s , to the ratio between capital and entrepreneurial net worth, k . This relationship is the key feature of the financial accelerator.

To determine $\bar{\omega}$, we proceed as follows. The aggregate return on capital in steady state, implied by (2.11), is given by

$$R^k = \alpha XY/K + (1 - \delta),$$

while steady-state net worth is given by

$$N = \iota V + (1 - \alpha - \Omega)XY,$$

where $V = (1 - \Gamma(\bar{\omega})) R^k Q K$. Combining these expressions implies

$$\beta/k(\bar{\omega}) = \iota(1 - \Gamma(\bar{\omega}))s(\bar{\omega}) + \frac{1 - \alpha - \Omega}{\alpha}(s(\bar{\omega}) - \beta(1 - \delta)), \quad (\text{A5})$$

so that $\bar{\omega}$ can be determined for given values of $(\Omega, \alpha, \beta, \delta, \mu, \iota, \sigma_\omega^2)$.

B. Log-linearization

All derivations in the previous subsection pertain to the non-stochastic steady state of the model. However, BGG establish that, with the addition of aggregate uncertainty, a positive relationship between the external finance premium and the capital to net worth ratio continues to hold. Specifically, this relationship can be written as

$$\frac{Q_t K_{t+1}}{N_{t+1}} = \psi \left(\frac{E_t R_{t+1}^k}{R_{t+1}} \right). \quad (\text{A6})$$

As in steady-state equation (A4) above, therefore, (A6) provides a link between the entrepreneur's demand for physical capital relative to his current net worth and the wedge between the expected return to capital, $E_t R_{t+1}^k$, and the safe rate, R_{t+1} . Log-linearizing (A6) gives

$$K/N(q_t + k_{t+1} - n_{t+1}) = \psi' \left(R^k/R \right) R^k/R (E_t r_{t+1}^k - r_{t+1}) \quad (\text{A7})$$

or

$$E_t r_{t+1}^k - r_{t+1} = -\chi(n_{t+1} - q_t - k_{t+1}), \quad (\text{A8})$$

where $\chi = \frac{\psi(R^k/R)}{\psi'(R^k/R)} \frac{R}{R^k}$. Note that while the precise functions ψ and ψ' are unknown, the relevant steady-state values can be readily obtained as follows. Define g as the function that relates $\bar{\omega}$ to s given by (A2) and h as the function that relates $\bar{\omega}$ to k given by (A3). The respective derivatives are as follows:

$$\begin{aligned} g' &= \frac{\lambda' \Upsilon - \lambda \Upsilon'}{\Upsilon^2}, \\ h' &= \frac{\Upsilon'(1 - \Gamma) + \Upsilon \Gamma'}{(1 - \Gamma)^2}. \end{aligned}$$

Thus we have $k = \psi(s) = h(g^{-1}(s))$ and $\psi'(s) = h'/g'$, implying that

$$\chi = \frac{\psi(R^k/R)}{\psi'(R^k/R)} \frac{R}{R^k} = \frac{g'k}{h's} = \frac{\lambda'/\lambda - \Upsilon'/\Upsilon}{\Upsilon'/\Upsilon + \Gamma'/(1-\Gamma)},$$

where all functions are evaluated at the threshold value $\bar{\omega}$ determined by (A5).

C. Numerical Implementation

Apart from the parameters α, β, δ and Ω , which are calibrated from first moments of the data and thus taken as given throughout, the microfoundations of the financial accelerator were shown to depend on three additional parameters: σ_ω^2 , the variance of idiosyncratic shocks to the return on capital; μ , the percentage rate of bankruptcy costs; and ι , the entrepreneurs' natural rate of survival. The combination of these parameters determines, in a non-trivial way, the relevant steady-state variables of the model and implies a value for χ , the "reduced form" parameter capturing financial frictions. As we cannot identify σ_ω^2, μ and ι separately and therefore estimate χ instead, we have to make an assumption as to which values of the former should be attributed to a specific value of the latter. This is important to ensure consistency between a given value of χ and the steady-state values imposed during estimation. Implicitly, we are thus making the steady state of the model (or, more precisely, those steady-state values not already pinned down otherwise) a function of χ , by attributing to each possible value of χ a precise combination of deep parameters. The range of possible choices is substantially narrowed by three simultaneous considerations. First, the "deep" parameters σ_ω^2, μ and ι should be realistic in their own right. In practice, we would thus like to set them close to the values proposed by BGG. Second, variations in the deep parameters should allow χ to take on any possible value between 0 and, say, 0.1, reflecting every possible situation between no and very strong financial frictions. Finally, in any of these situations, steady-state values themselves should be realistic, i.e. imply sensible magnitudes for default probabilities, monitoring expenditure, the net worth to capital ratio and output shares. As a guideline, we consider again the values put forward by BGG, e.g. a net worth to capital ratio of 0.5, which in turn implies a plausible ratio of corporate debt to GDP of around one. Requiring all three aspects leaves little other possibility than associating changes in χ with simultaneous changes in μ and ι . In particular, variation in only one of the deep parameters would imply unrealistically large deviations from the steady-state values posited by BGG. Thus, we fix σ_ω^2 at 0.27, essentially equal to BGG, and associate variations in χ between 0 and nearly 0.1 with simultaneous, proportionate variation in μ between 0 and 0.4, and $(1 - \iota)$ between 0.012 and 0.03. The latter interval is symmetric about BGG's choice of 0.021, while the interval for μ comprises BGG's choice of 0.12 and covers all cases between no and very substantial monitoring costs. Thus specified, the steady-state risk premium can take values between 0 and 4 % p.a., with a center point of 2 % precisely when financial frictions are close to the level assumed in BGG. Although the other crucial steady-state values do not vary much with χ , as desired, we still

ensure in our estimation that they are updated at each step in order to be consistent with the microfoundations. In addition, we ascertained that the paper's main findings are actually not affected by the steady-state adjustment just described. As an important example, the insignificance of the parameter governing financial frictions is perfectly robust to the omission of any steady-state adjustment. Specifically, when we repeat the relevant distance metric test reported in table 3, but now maintaining all steady-state values implied by the unrestricted point estimate for χ (from table 1), the test statistic remains minuscule and does not allow to reject the null of no financial frictions.

B Tables and Figures

Table 1: Estimates of structural parameters - baseline model

Parameter	Meaning	Efficient Weighting	Diagonal Weighting
λ_p	price rigidities (low λ_p = strong rigidities)	0.0034 (0.0017)	0.0032 (0.0037)
κ_p	price indexation	1.0000 ---	0.8965 (0.3171)
λ_w	wage rigidities (low λ_w = strong rigidities)	0.0160 (0.0100)	0.0249 (0.0174)
κ_w	wage indexation	1.0000 ---	1.0000 ---
χ	financial accelerator	0.0672 (0.0453)	0.0616 (0.1390)
φ	capital adjustment costs	0.6464 (0.1594)	0.5075 (0.5072)
σ	power utility parameter	3.6382 (1.1576)	4.0967 (3.6763)
γ	consumption habits	0.1206 (0.2897)	0.2659 (0.7877)
loss function		30.99	16.31

Table 2: Robustness checks for baseline specification (efficient weighting)

Parameter	match 8 quarters	match 16 quarters	$v = 1$	$v = 5$
λ_p	0.0031 (0.0022)	0.0039 (0.0018)	0.0033 (0.0016)	0.0034 (0.0017)
κ_o	1.0000 ---	1.0000 ---	1.0000 ---	1.0000 ---
λ_w	0.0181 (0.0118)	0.0164 (0.0099)	0.0425 (0.0281)	0.0097 (0.0058)
κ_w	1.0000 ---	1.0000 ---	1.0000 ---	1.0000 ---
χ	0.0622 (0.0467)	0.0735 (0.0395)	0.0723 (0.0449)	0.0653 (0.0453)
φ	0.6302 (0.1774)	0.6627 (0.1576)	0.6772 (0.1648)	0.6348 (0.1578)
σ	3.2413 (1.1218)	3.6928 (1.1694)	3.7168 (1.1790)	3.6092 (1.1554)
γ	0.1795 (0.2803)	0.1019 (0.2929)	0.1261 (0.2868)	0.1192 (0.2905)

Table 3: Estimates and distance metric tests for restricted models

Parameter	$\gamma = 0$	$\gamma = 1$	$\varphi = 0$	$\chi = 0$
λ_D	0.0033 (0.0016)	0.0012 (0.0010)	5.1861 (3.8438)	0.0015 (0.0007)
κ_D	1.0000 ---	1.0000 ---	0.0000 ---	1.0000 ---
λ_w	0.0158 (0.0100)	0.0283 (0.0155)	0.0005 (0.0004)	0.0176 (0.0098)
κ_w	1.0000 ---	1.0000 ---	0.0000 ---	1.0000 ---
χ	0.0676 (0.0446)	0.0000 ---	0.0000 ---	
φ	0.6442 (0.1560)	0.5658 (0.1226)		0.4358 (0.0860)
σ	3.6861 (1.1649)	16.0261 (117.4123)	4.6993 (1.6805)	5.3823 (1.8252)
γ			0.0000 ---	0.0437 (0.3245)
loss function	31.28	43.80	190.05	32.85
test statistic	0.29	12.81	159.06	1.86
p-value	0.5932	0.0003	0.0000	0.1729

Figure 1: Empirical Characterization of Monetary Policy Transmission

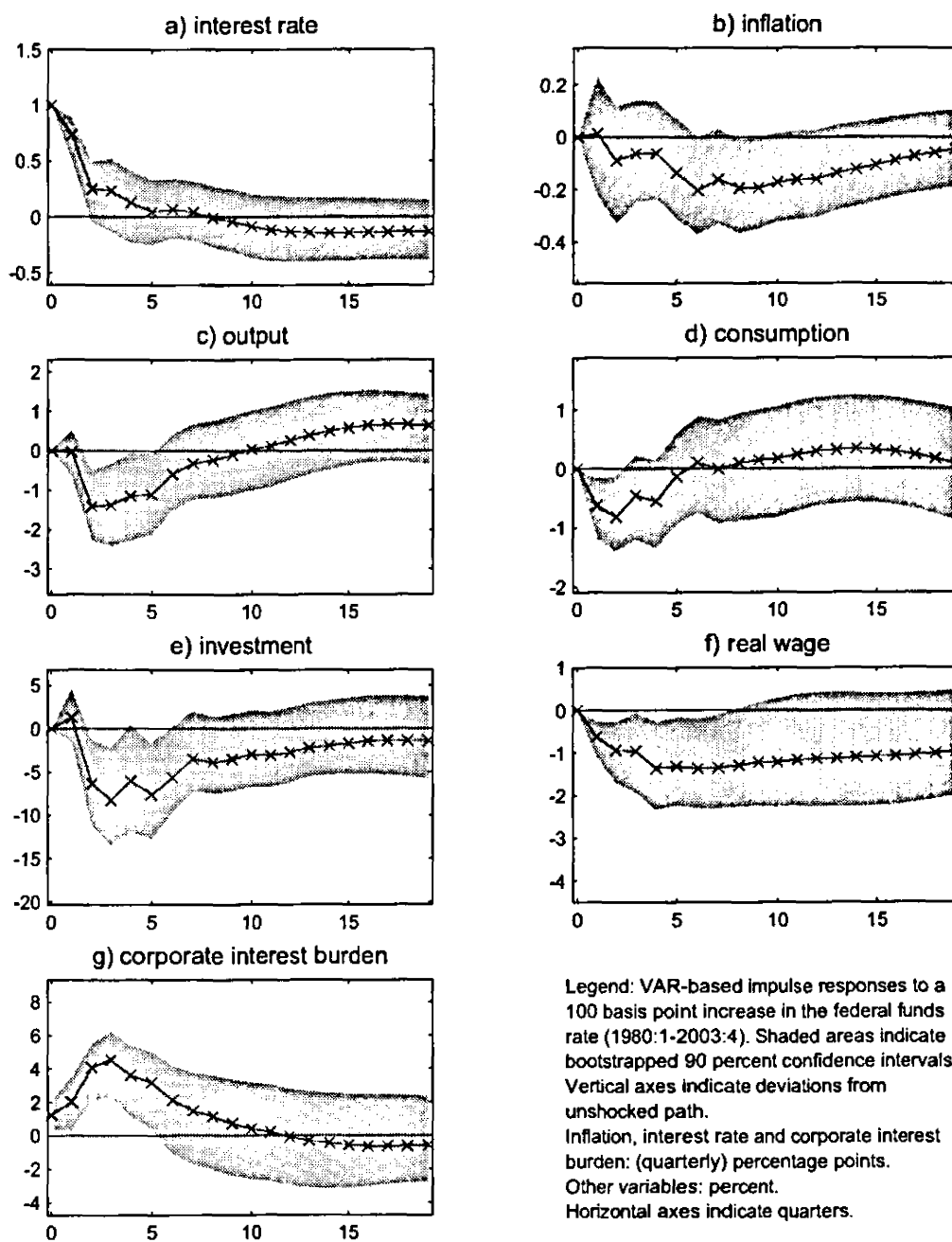
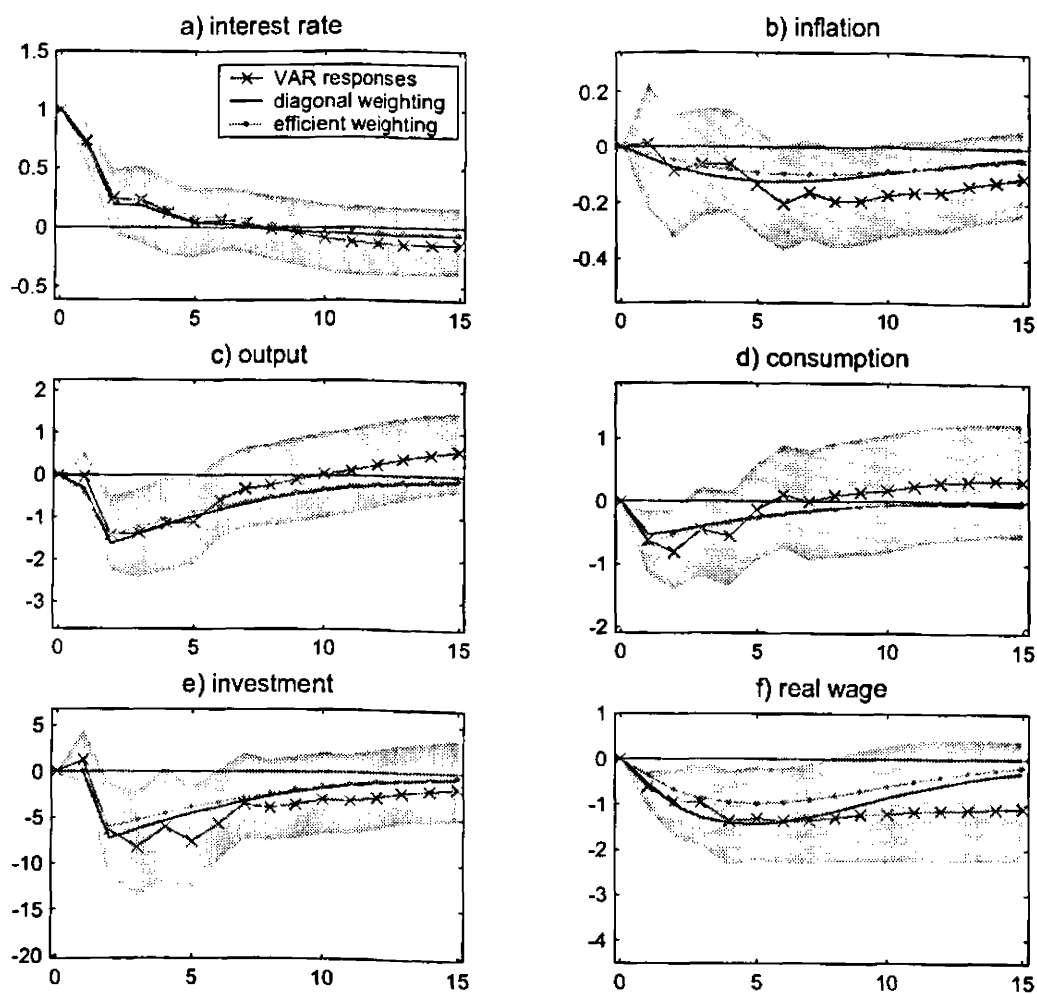
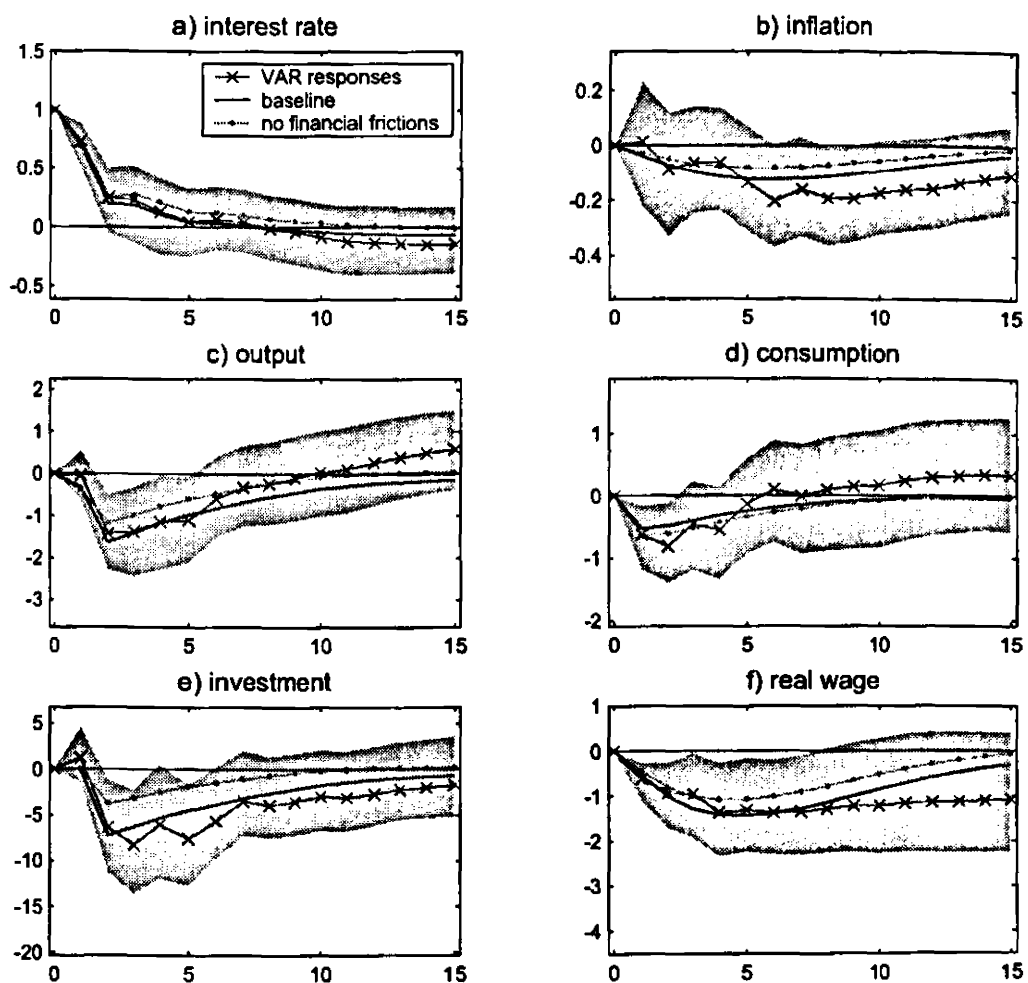


Figure 2: Impulse responses of estimated VAR and DSGE model



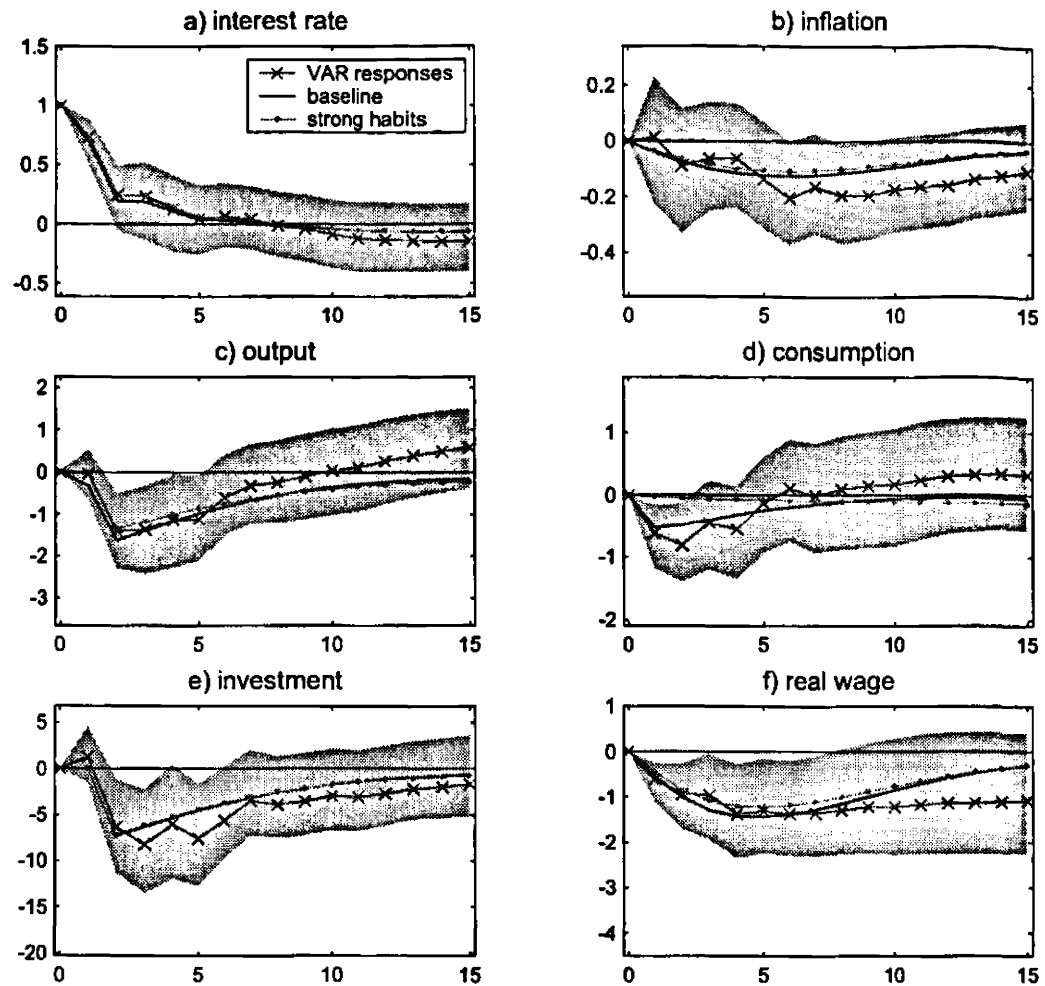
Legend: Impulse responses to a 100 basis point increase in the federal funds rate in VAR and estimated DSGE model (see legend of figure 1). Responses of estimated DSGE model differ according to the weighting matrix employed as discussed in the main text.

Figure 3: The Role of Financial Frictions



Legend: Impulse responses to a 100 basis point increase in the federal funds rate according to VAR and DSGE model. Baseline: model responses computed for parameter estimates obtained on the basis of diagonal weighting. No financial frictions: χ set to zero, other parameters unchanged.

Figure 4: The Role of Habits



Legend: Impulse responses to a 100 basis point increase in the federal funds rate according to VAR and DSGE model. Baseline: model responses computed for parameter estimates obtained on the basis of diagonal weighting. Strong habits: γ set to one, other parameters unchanged.

Chapter 3

Asset Market Participation, Monetary Policy and the Effects of US Government Spending: What accounts for the Declining Fiscal Multiplier? (with Florin Bilbiie and André Meier)

3.1 Introduction

One of the most prominent issues in macroeconomics concerns the effects of an increase in government spending. The topic takes center stage in the policy debate and has received great attention in the theoretical literature at least since Keynes' General Theory. Recently, empirical research dealing with this question has flourished, as well. In a seminal study based on Vector Autoregressions (VAR) for a long post-war sample, Blanchard and Perotti (2002) provide evidence indicating a positive response of consumption and output to a one-time fiscal shock. Specifically, the authors analyze US time series data from 1960 to 1997 and report a spending multiplier for consumption between one third and one. Similar findings were also obtained by Fatás and Mihov (2001) and Galí, López-Salido and Vallés (2004).

On the theoretical side, although standard business cycle models have difficulty explaining this evidence, several recent papers have presented models that can account for the 'crowding-in' of consumption, along with a positive response of the real wage and the positive co-movement of consumption and hours found in the data. One important assumption driving their results pertains to the presence of some so-called 'rule-of-thumb' consumers who, rather than optimizing intertemporally, simply consume their entire disposable income in a given period. For these

consumers, the expectation of increased future taxes does not counteract the current effects of higher government spending, so their consumption may actually increase following a government spending shock. The idea was popularized in a paper by Mankiw (2000) and subsequently taken up by Galí, López-Salido and Vallés (2004) and Bilbiie and Straub (2004), thus helping to bring the theory in line with what the data seemed to show.

More recent empirical studies, however, suggest that the transmission of fiscal policy shocks has actually changed around the time of the early 1980s. Indeed, both Perotti (2005) and Mihov (2003) provide fresh VAR-based evidence showing a substantial reduction in the effects of spending shocks after 1980. Perotti, for instance, considers five OECD countries including the US and finds that the responses of both output and consumption have been significantly smaller and less persistent in the post-1980 compared to the pre-1980 period.

Why have the expansionary effects of US fiscal policy diminished over time? The fact that the aforementioned studies consistently point to a break date around 1980 suggests several interesting hypotheses. First, it is widely accepted that the conduct of monetary policy differed substantially before and after the 1980s. This change may, of course, have affected the transmission of shocks in the economy quite generally. A second hypothesis draws on the observation that fiscal policy itself has changed. Perotti (2005), for example, reports that a typical shock to government spending tends to display much less persistence in the later sample. A third explanation addresses the behavior of the private sector, by pointing out the possible consequences arising from a pronounced increase in asset market participation. Indeed, there is strong evidence, presented in Mishkin (1991), that households' asset holdings were subject to several restrictions until the late 1970s and that assets typically held by small savers were not linked to market interest rates. Bilbiie (2004) argues that these constraints may have effectively prevented a considerable fraction of households from participating in asset markets, thus hampering these households' capacity to smooth their consumption in the desired way. However, due to both market deregulation and financial innovation in the early 1980s, many of the legal and quantitative restrictions on households' financial business progressively disappeared: 'Regulation Q', which imposed severe restrictions on the interest paid by commercial banks, was phased out; a reduced minimum denomination of Treasury bills made these assets available to a larger class of savers; money market mutual funds started prospering; trading costs at the stock exchanges decreased sharply; and shareholding became much more widespread - to name but a few of the developments occurring around the time. Generally, the introduction and widespread use of new financial instruments and the elimination of ceilings on deposit rates had the clear effect of (re-)linking saving decisions to market interest rates. The underlying institutional changes may, thus, have reduced the number of households who previously did not use asset markets to smooth their consumption profiles. As a bottom line, changes in private-sector finance complement monetary and fiscal policies as candidate causes for the observed decline in the effects of US government spending.

The goal of the present paper is to evaluate the relative promise of these dif-

ferent explanations. A better understanding of how and why fiscal transmission changed during the early 1980s would seem valuable also in view of the more general changes in business cycle behavior occurring around that time. In fact, several recent studies of US macroeconomic data have highlighted a marked decrease in the volatility of economic activity since the mid-1980s. Kim and Nelson (1999) and McConnell and Perez-Quiros (2000) were the first to note a significant moderation of output fluctuations, along with an improved forecastability of growth rates, from roughly 1984 onwards. Several subsequent papers, including Stock and Watson (2003) and Ahmed, Levin and Wilson (2004), have attempted to explain the sources of this "Great Moderation". Possible explanations include improved policy-making, changes in the behavior of the private sector, and a more benign economic environment in terms of exogenous shocks. Although in this paper we focus on one (fiscal) shock only and thus cannot address all candidate causes of the Great Moderation, our analysis will also contrast policy changes with changes in private-sector behavior, potentially allowing for interesting insights into the relative importance of these two factors.

To shed light on the question of diminishing fiscal-policy effectiveness and to evaluate the competing hypotheses we proceed in the following way. We begin by adding to the empirical evidence on fiscal transmission provided by Perotti (2005) and Mihov (2003). Specifically, we estimate structural VARs on US time series for 1957:1-1979:2 ('S1') and 1983:1-2004:4 ('S2') and document the aforementioned reduction in the strength and persistence of fiscal policy effects on output, wages and private consumption. S1 and S2 constitute appropriate samples for our study, because they allow us to characterize fiscal policies *before* and *after* any of the potentially important changes (to monetary policy, government spending, financial markets, and the business cycle quite generally) that were discussed above. In the second step, we introduce a dynamic stochastic general equilibrium (DSGE) model featuring price rigidities, monetary and fiscal policy as well as non-asset holding households. Thus, the model nests all three possible explanations for differences in fiscal-policy effectiveness across samples. Given that economic interest centrally bears on the impulse response functions associated with a government spending shock, it is natural to consider this statistic as the critical nexus between theory and data. In a third step, we therefore rely on a minimum distance strategy that matches impulse responses from the theoretical model with those obtained from the VARs. This procedure provides us with well-defined estimates for the parameters of our model for both samples and thereby allows us to judge the quantitative importance of changes in both household behavior and government policies. Similar estimation methods have been employed by several other authors, although mostly in the context of monetary policy analysis. The most prominent examples are Rotemberg and Woodford (1997) and Christiano, Eichenbaum and Evans (2005). The first application to the context of fiscal policy is provided in a paper by Bouakez and Rebei (2003).¹ Addressing a recent criticism by Chari, Kehoe, McGrattan (2005) and oth-

¹ While these authors are also interested in the response of private consumption to a government

ers, we ensure that the dynamics of our theoretical model are fully nested in the VAR, so that the typical problem of omitted state variables does not arise.

For the purposes of our comparative exercise, we estimate the model for both samples and allow policy parameters and the extent of asset market participation to vary, while all deep parameters (governing preferences and technology) are assumed to remain unchanged across periods. Monetary policy is characterized by a simple interest rate feedback rule, while fiscal policy is described by two parameters governing the persistence of government spending as well as a deficit rule. Overall, the parameter estimates of our model confirm that asset market participation has increased considerably after 1980. Our results on monetary policy align with the consensus view that the FED has taken a tougher stand on inflation after 1980. In addition, the estimates characterizing fiscal policy are also quite different across samples, implying that government spending shocks have become less persistent and more deficit-financed in S2. To assess the individual impact of these changes on the transmission of fiscal shocks, we run counterfactual experiments. Keeping all deep parameters constant, we investigate which of the changes between the two samples may have been pivotal for the diminishing fiscal multiplier.

We find that increased *asset market participation* and changes in *fiscal policy* parameters account for some of the decline in the effects of government spending; importantly, they seem crucial in explaining changes in the *intertemporal path* of the responses, and in particular in their persistence. Changes in *monetary policy* appear to be the key factor in explaining the change in absolute *magnitude* of the effects at any given point in time, but do not seem to explain the change in the shape of the impulse responses.

The rest of this paper is structured as follows. In section 2, we introduce our model, i.e. the stylized economy for which we obtain theoretical impulse responses. Section 3 looks at the empirical counterpart, presenting our data, our structural VAR and the associated empirical impulse responses. Our estimation strategy is detailed in section 4, which is followed by a discussion of the results in section 5. In section 6, we present several counterfactual experiments that shed some light on the importance of different explanations for our findings. Finally, section 7 summarizes the paper and provides a conclusion.

3.2 The Model

The model, which draws on both Galí, López-Salido and Vallés (2004) and Bilbiie and Straub (2004), is a standard cashless DSGE model with sticky prices that, in addition, features limited asset market participation.² Apart from a continuum of

spending shock, their analysis is based on a model featuring strong Edgeworth complementarity between private and public spending. Relying essentially on preferences to explain the crowding-in of consumption, this framework strikes us as less suitable for addressing changes in the transmission of fiscal policy over time.

²Appendix C shows that the explicit introduction of money into our model would, under reasonable assumptions, not affect our theoretical results on the importance of limited asset market

households, there is a continuum of monopolistically competitive producers which set prices on a staggered basis. Moreover, the model specifies two policy-makers. A monetary authority sets its policy instrument, the nominal interest rate. A fiscal policy authority purchases the consumption good, raises lump-sum and income taxes and issues nominal debt.

3.2.1 Households

There is a continuum of households $[0, 1]$ consuming the final good. We assume that a fraction $1 - \lambda$ of households smooth consumption by participating in asset markets - these households are '*asset holders*'. Specifically, they trade a riskless one-period bond and hold shares in firms. The rest of the households on the $[0, \lambda]$ interval do not participate in asset markets - we dub them '*non-asset holders*'. This distinction between households is assumed to arise not from preferences but from their actual capacity (or lack thereof) to participate in asset markets, as in Bilbiie (2004).³ The most important reasons for limited asset market participation appear to be concrete institutional constraints like the ones described in Mishkin (1991). While we do not take a stand as to what are the deep reasons underlying such institutional constraints, we view this feature as a plausible aspect of reality and try to assess its empirical relevance in explaining the effects of government spending shocks.

Asset holders

Each asset holder on the $[\lambda, 1]$ interval chooses consumption $C_{A,t}$, leisure $L_{A,t}$ and nominal bond holdings $B_{A,t+1}$ by solving the following intertemporal problem:

$$\max E_t \sum_{s=0}^{\infty} \beta^s \frac{(C_{A,t+s} L_{A,t+s}^\varphi)^{1-\sigma}}{1-\sigma} \quad (3.1)$$

subject to the budget constraint

$$R_t^{-1} B_{A,t+1} + P_t C_{A,t} + P_t T_t = B_{A,t} + (1 - \tau)(W_t N_{A,t} + P_t D_{A,t}), \quad (3.2)$$

where $\beta \in (0, 1)$ denotes the discount factor. R_t is the gross nominal return on bonds purchased in period t , P_t denotes the price level, W_t the nominal wage, and $D_{A,t}$ represents real dividend payments to households who own shares in the monopolistically competitive firms. $N_{A,t}$ are hours worked by the asset holder; they are given by $N_{A,t} = 1 - L_{A,t}$, where time endowment has been normalized to one. We further assume that the income tax rate τ is constant, and that real lump-sum taxes T_t are adjusted according to a rule specified below. Note that the utility function in (3.1)

participation in explaining the effects of government spending shocks.

³This assumption is also made in the 'liquidity effect' literature - see e.g. Alvarez, Lucas and Weber (2002). The terminology follows Vissing-Jorgensen (2002). In contrast, Galí et al. and Mankiw (2000) distinguish households by their ability to hold physical capital.

is non-separable in consumption and leisure and belongs to the King-Plosser-Rebelo class, being consistent with balanced growth. Maximizing utility (3.1) subject to (3.2) implies the first order conditions

$$R_t^{-1} = \beta E_t [\Lambda_{t,t+1}], \quad (3.3)$$

$$\text{where } \Lambda_{t,t+s} = \left(\frac{C_{A,t}}{C_{A,t+s}} \right)^\sigma \left(\frac{L_{A,t+s}}{L_{A,t}} \right)^{\varphi(1-\sigma)} \frac{P_t}{P_{t+s}}, \quad (3.4)$$

$$\text{and } \frac{C_{A,t}}{L_{A,t}} = \frac{1-\tau}{\varphi} \frac{W_t}{P_t}. \quad (3.5)$$

Non-asset holders

Non-asset holders choose consumption $C_{N,t}$ and hours $N_{N,t}$ in each period t by solving the intratemporal problem

$$\max \frac{(C_{N,t} L_{N,t}^\varphi)^{1-\sigma}}{1-\sigma} \quad (3.6)$$

subject to the condition that consumption expenditure equal net income,

$$P_t C_{N,t} = (1-\tau) W_t N_{N,t} - P_t T_t. \quad (3.7)$$

The first order condition associated with (3.6) is given by

$$\frac{C_{N,t}}{L_{N,t}} = \frac{1-\tau}{\varphi} \frac{W_t}{P_t}. \quad (3.8)$$

Note that we have assumed preference homogeneity: φ and σ are the same for both types of households. This is consistent with the view that the only source of heterogeneity among households is their access to asset markets, which can be limited due to exogenous institutional constraints. We also assume that hours worked in steady state are the same for both types of households, $N_A = N_N = N$. Because of preference homogeneity, this requires that steady-state asset income be zero so that consumption shares are equal across groups, $C_A = C_N = C$. See Appendix A for details.

3.2.2 Firms

Final output is produced by a representative competitive firm. This firm purchases differentiated intermediate goods $i \in [0, 1]$ from monopolistically competitive producers and combines them into the final good. The aggregation technology is of the CES form, with ε denoting the constant elasticity of substitution:

$$Y_t = \left(\int_0^1 Y_t(i)^{\frac{\varepsilon-1}{\varepsilon}} di \right)^{\frac{\varepsilon}{\varepsilon-1}}, \quad (3.9)$$

where $Y_t(i)$ denotes the quantity used of differentiated good i at time t . The final-goods firm maximizes profits $P_t Y_t - \int_0^1 P_t(i) Y_t(i) di$, where P_t is the overall price index for the final good and $P_t(i)$ denotes the price of intermediate good i . This implies a downward-sloping demand curve for each intermediate input:

$$Y_t(i) = (P_t(i) / P_t)^{-\epsilon} Y_t, \quad (3.10)$$

while the price index is given by $P_t = \left(\int_0^1 P_t(i)^{1-\epsilon} di \right)^{1/(1-\epsilon)}$.

The monopolistically competitive producers of intermediate goods face a technology which is linear in labor and subject to a fixed cost F :

$$Y_t(i) = N_t(i) - F, \text{ if } N_t(i) > F, \text{ otherwise } Y_t(i) = 0. \quad (3.11)$$

The share of the fixed cost F in steady-state output governs the degree of increasing returns to scale. Real profits of a generic firm are thus given by $O_t(i) \equiv [P_t(i) / P_t] Y_t(i) - [W_t / P_t] N_t(i)$. Following Calvo (1983) and Yun (1996), intermediate-good firms are assumed to adjust their prices infrequently. We define α as the probability of keeping the price constant in a given period. This exogenous probability is independent of past price adjustments. Accordingly, with probability $(1 - \alpha)$, the firm is able to reoptimize and change its price. Given this possibility, a generic firm i will set $P(i)$ in order to solve

$$\max E_t \sum_{s=0}^{\infty} \alpha^s \Lambda_{t,t+s} [P_t(i) Y_{t,t+s}(i) - W_{t+s} Y_{t,t+s}(i)]$$

subject to the demand function (3.10). Recall from (3.4) above that $\Lambda_{t,t+s}$ denotes the stochastic discount factor characterizing asset holders, who own the firms. The first order condition for this problem is given by

$$E_t \sum_{s=0}^{\infty} \alpha^s \Lambda_{t,t+s} \left(P_t(i) - \frac{\epsilon}{\epsilon - 1} W_{t+s} \right) = 0 \quad (3.12)$$

In equilibrium each producer who sets a new price $P_t(i)$ in period t will choose the same price and the same level of output.

3.2.3 Monetary policy

Monetary policy is characterized by an interest rate feedback rule whereby the nominal interest rate R_t is a function $\Phi(\cdot)$ of expected inflation:

$$R_t = \Phi(E_t \Pi_{t+1}), \quad (3.13)$$

where $\Pi_{t+1} \equiv P_{t+1} / P_t$ denotes gross inflation between t and $t + 1$. The constant elasticity of this function, ϕ_π , governs the response of interest rates to expected inflation.

3.2.4 Fiscal policy

The fiscal authority purchases consumption goods, G_t , raises distortionary and lump-sum taxes and issues debt, B_{t+1} , consisting of one-period nominal discount bonds. The government budget constraint reads as

$$R_t^{-1}B_{t+1} = B_t + P_t [G_t - \tau Y_t - T_t]. \quad (3.14)$$

Letting $g_t = \frac{G_t - G}{G}$, with letters without time subscript denoting steady state values, we assume that government spending follows an exogenous AR(2) process,

$$g_t = \rho_1 g_{t-1} + \rho_2 g_{t-2} + \varepsilon_t, \quad (3.15)$$

which allows for a hump shaped response of spending to a spending innovation ε_t .

The financing of government spending is determined by a deficit rule. Thus, let $D_t = G_t - T_t - \tau Y_t$ denote the primary deficit, i.e. total non-interest spending less revenues. We also define the *structural* deficit, $D_{s,t}$, as the primary deficit adjusted for automatic responses of tax revenues resulting from deviations of output from its steady-state value: $D_{s,t} = D_t + \tau(Y_t - Y) = G_t - T_t - \tau Y$. To ensure consistency with the empirical counterpart of the model (and for ease of comparison with other empirical studies), we divide the deficit and debt variables by output Y_t .⁴ Letting $\hat{d}_{s,t}$ denote a first order Taylor approximation of $D_{s,t}/Y_t$ around the steady state, we assume that the structural deficit is adjusted according to the following rule:

$$\hat{d}_{s,t} = \eta \hat{d}_{s,t-1} + \phi_g G_Y g_t + \phi_b \hat{b}_t, \quad (3.16)$$

where $\hat{b}_t \equiv B_t / (P_{t-1} Y_{t-1})$ is real debt divided by last period's output, in order to remain a state variable. Rules of this type have been studied extensively, see e.g. Bohm (1998) and Galí and Perotti (2003). The parameter η captures the possibility that budget decisions are autocorrelated, while the parameter ϕ_g measures the degree of deficit finance of temporary increases in government spending. For ease of interpretation, we rescale the coefficient on spending with the steady-state share of government spending in output, G_Y such that all variables are in output units. Finally, the parameter ϕ_b governs the response of the deficit to the beginning-of-period ratio of debt to GDP, hence capturing a 'debt stabilization' motive: a negative value of ϕ_b indicates that deficits are adjusted in order to stabilize outstanding debt.

3.2.5 Equilibrium, market clearing and aggregation

A rational expectations equilibrium is a sequence of processes for all prices and quantities introduced above such that the optimality conditions hold for all agents and all markets clear at any given time t . Specifically, market clearing requires that

⁴Note that, since we assume that in steady-state debt and deficits are zero, first-order variations in any of these variables around the steady state are isomorphic to those of variables defined as shares of steady state output. For example, if say $X = 0$, up to first order around this steady-state we have $X_t/Y_t \simeq X_t/Y$.

labor demand equal total labor supply, $N_t = \lambda N_{N,t} + (1 - \lambda) N_{A,t}$, all profit income be distributed as dividends to shareholders (asset holders) and all government debt be held by asset holders, $B_{t+1} = (1 - \lambda) B_{A,t+1}$. By Walras' law, then, the goods market also clears: $C_t + G_t = Y_t$, where aggregate consumption is $C_t \equiv \lambda C_{N,t} + (1 - \lambda) C_{A,t}$. We solve numerically a locally approximate (log-linear) version of the model around its non-stochastic steady state, see Appendix B for details.

3.2.6 Government spending shocks and consumption

This subsection describes the intuition behind fiscal policy transmission in the model outlined above. To start with, consider the case in which utility is separable ($\sigma \rightarrow 1$).⁵ Note that an increase in government spending will generally depress the consumption of asset holders because of a negative wealth effect resulting from the induced increase in the tax burden (in present value terms). In the case of an active monetary policy, i.e. for $\phi_\pi > 1$, there is an additional substitution effect operating in the same direction; this is triggered by an increase in the real interest rate as the increase in government spending leads to a rise in inflation. These channels of transmission are at the heart of the analysis of fiscal transmission in standard business cycle models, e.g. Baxter and King (1993) and Linnemann and Schabert (2003). They generally induce a crowding out of private consumption in response to increases in government spending.

In contrast, in the present model it is possible for total private consumption to increase, the basic mechanism relying upon a strong enough increase in the real wage. In fact, a higher real wage induces an increase in the consumption of non-asset holders which may eventually more than offset the fall in the consumption of asset holders.

The response of the real wage naturally depends on the interplay of labor supply and demand. To begin with, a government spending shock increases the demand for goods. With sticky prices à la Calvo, this has an effect on labor demand: firms who cannot change their price will adjust quantities, hence shifting labor demand at a given wage (the rest of the firms will increase their prices, creating inflation). This effect is larger, the larger the degree of price stickiness (and is absent with flexible prices).

Labor supply shifts for two different reasons. First, there is a direct income effect on the labor supply of non-asset holders who are willing to work more as the tax burden increases.⁶ This shift can be avoided on impact if spending is deficit-financed - the path of taxation matters for non-asset holders. Second, asset holders also increase labor supply for a given wage: this is due both to the wealth effect - asset holders internalize the government budget constraint - and to intertemporal substitution. The latter effect occurs if an increase in inflation triggers an increase

⁵The resulting model is essentially the same as the lump-sum taxes version of Bilbiie and Straub (2004), on which the following discussion draws.

⁶In Appendix B we detail how the reduced-form labor supply of non-asset holders is a function of the real wage and lump sum taxes.

in the real interest rate, thus providing incentives for asset holders to postpone consumption. Consequently, the overall shift in labor supply is smaller, the smaller: i) the persistence of the government spending shock: lower persistence reduces the present discounted value of taxes and the wealth effect on asset holders; ii) the degree of monetary policy activism: a less aggressive monetary policy implies a lower real interest rate and thereby weakens asset holders' incentives to postpone consumption; and iii) the degree of deficit financing: deficit financing reduces the wealth effect on non-asset holders.

When the shift in labor demand dominates the shift in labor supply (which also requires that the latter be sufficiently inelastic), a high enough increase in the real wage may obtain so that aggregate consumption increases. Note, however, that a strong increase in the real wage does not necessarily lead to a rise in aggregate consumption. In fact, such a change also brings about a high increase in marginal costs and a fall in profits, so the consumption of asset holders decreases by more. Furthermore, while deficit financing works towards ensuring a positive consumption response in most cases, this is not a general result. Due to limited asset market participation, deficits have a negative effect on asset holders' consumption above and beyond the standard wealth effect associated with the present discounted value of government spending. Specifically, an increase in debt siphons further resources away from the potential consumption of asset holders, since they will end up holding all debt issued by the government. For asset holders, this amount - in per capita terms - exceeds the debt level of the government by a factor of $\lambda/(1-\lambda)$, because non-asset holders do not hold any debt.

When utility is non-separable ($\sigma \neq 1$), there is an additional channel changing the co-movement between consumption and hours of asset holders. Specifically, if $\sigma > 1$, hours and consumption will co-move positively: for a given increase in the real wage, asset holders substitute out of leisure into consumption. In particular, the negative wealth effect that induces an increase in hours worked can also induce an increase in consumption. Moreover, $\sigma > 1$ reduces the elasticity of asset holders' consumption to real interest rate movements, since it implies a lower elasticity of intertemporal substitution. This, in turn, means that asset holders have weaker incentives to postpone consumption for a given increase in real interest rates.

All things considered, the discussion makes clear that even a relatively parsimonious specification may generate quite complex interactions between the different features of the model.⁷ In our view, this further increases the promise of estimating the model's parameters by means of a minimum-distance procedure that ensures the greatest possible match between the model's theoretical predictions and important empirical regularities in the data.

⁷ All the effects described in this paragraph can be clearly seen from the loglinearized version of the Euler equations in Appendix B.

3.3 Empirical Characterization of Transmission

3.3.1 VAR specification

Having introduced our theoretical model, we now turn to the empirical characterization of fiscal transmission, i.e. the effects of a temporary increase in government spending as apparent from the data. Specifically, we use a VAR framework to obtain estimates of the empirical impulse response functions associated with a government spending shock.

As our goal is to estimate the structural parameters of our model by minimizing the distance between theoretical and empirical impulse responses, we have to ensure that the VAR actually captures the empirical equivalent of the dynamics implied by our theory. In other words, the log-linear model ought to be nested in our VAR. This has two implications. First, the identifying restrictions we use in our VAR have to be consistent with the model. In the VAR literature on fiscal transmission, shocks to government spending have been identified on the assumption that government spending is not contemporaneously affected by the other variables included in the VAR.⁸ We rely on the same identifying assumption, thereby nesting the model, where government spending is assumed to follow an exogenous AR(2) process. Moreover, like in the model, we allow all variables in the VAR to respond contemporaneously to government spending shocks. Specifically, we give a structural interpretation to the shocks obtained from a recursive VAR where government spending is ordered first, see Stock and Watson (2001). Following Perotti (2005), such a structural shock is interpreted as a random discretionary disturbance to government spending. This assumption can be justified from the observation that discretionary fiscal policy plausibly does not respond within a quarter to a change in the economy as reflected by an output innovation. Likewise, automatic stabilization is unlikely to occur within one quarter, given that our definition of government spending comprises government consumption and government investment but does not include transfer payments.

Second, the solution of the log-linearized model implies a state-space system in which all variables are functions of the current state only. The set of state variables in our model comprises current government debt and its lagged value along with the lagged value of output⁹, as well as the current value and first two lags of government spending. It is therefore desirable to include this set of variables in the VAR.¹⁰ Accordingly, government debt and government spending are the two fiscal variables in our VAR. As the real wage response plays an important role in the transmission

⁸See Blanchard and Perotti (2002), Fatás and Mihov (2001), Galí, López-Salido and Valles (2004), and Perotti (2005).

⁹Lagged debt and output appear as state variables since from the government budget constraint lagged structural deficit can be expressed as a function of these variables.

¹⁰This specification choice implicitly addresses the issue raised in a recent critique of the Structural VAR approach by Chari, Kehoe and McGrattan (2005). They show, using artificial data generated by an RBC model, that a VAR with four lags but without the state variable capital may be seriously misspecified. The fact that we include the relevant states in our VAR resolves this problem and ensures that the model dynamics are actually nested in the empirical specification.

of spending shocks, we also include this variable. Eventually, our VAR model comprises five variables: government spending, output, wages, private consumption, and government debt. Spending, output and consumption are expressed in logs of real per capita terms, real wages are in logs, and debt is given as share of output. We include four lags of each variable together with a constant and remove a linear time trend from all variables except the debt ratio.¹¹

As discussed above, earlier studies such as Blanchard and Perotti (2002) and Fatás and Mihov (2001) have reported a substantial increase in private consumption in response to a government spending shock.¹² However, new evidence by Perotti (2005) and Mihov (2003) suggests that the transmission of fiscal shocks changed substantially in the early 1980s. Most importantly, the response of consumption appears to have become considerably weaker. In order to trace these changes in fiscal policy, we consider a sample split around the year 1980, taking into account the possibility of structural breaks in other economic areas, as well. Specifically, given the prominent role of monetary policy in our subsequent analysis, we decide to end the first sample in 1979:2, i.e. just before the beginning of the Volcker chairmanship; the second sample then starts in 1983:1, i.e. just after the Volcker disinflation period. This split also seems appropriate with respect to the evidence on two other phenomena that are relevant for our study, namely the financial liberalization occurring in the early 1980s and the changes in business-cycle dynamics dated, again, in the early- to mid-1980s. Hence we estimate VARs on US time series data for the two samples: 1957:1-1979:2 (S1) and 1983:1-2004:4 (S2).

3.3.2 Empirical impulse responses

Figure 1 displays the impulse response functions of all five variables to a one percent increase in government spending for both S1 (left column) and S2 (right column). While the solid lines with dots indicate point estimates, the shaded areas represent

¹¹The data are drawn from several sources. From the National Income and Product Accounts (Bureau of Economic Analysis) we obtain real government spending, which is government consumption expenditures and gross investment (A822RX1). Real GDP (A191RX1) and real total personal consumption expenditures (A002RX1) are also taken from the NIPA. The real wage is obtained from the Bureau of Labour Statistics: Nonfarm business real hourly compensation (BLS: PRS84006153). Finally, end-of-period debt figures (total U.S. government debt privately held) come from the International Financial Statistics of the IMF (11188...ZF...). Private consumption, output and government spending are normalized by the current population level (NIPA: B230RC0).

¹²Note also that alternative identification schemes have generally led to less clear-cut results regarding the response of private consumption to a spending shock. Identification of fiscal shocks based on sign restrictions is suggested by Mountford and Uhlig (2004). They find that private consumption increases, but not significantly, in response to a deficit-financed government spending shock. In the case of a balanced-budget spending shock, consumption is observed to fall, but again not significantly. Yet another identification scheme is employed by Ramey and Shapiro (1998) and Edelberg, Eichenbaum and Fisher (1999), who study the response of economic time series to a dummy variable capturing fiscal episodes (Korean and Vietnam wars and Reagan military buildup). Both studies report mixed results regarding different components of private consumption expenditure at different horizons. Overall, the response of consumption to a fiscal episode is found to be small in this line of work.

symmetric 90 percent confidence intervals, computed by bootstrapping based on 1000 replications.

In the first row, the response of government spending can be seen to display greater persistence in S1 compared to S2. This is in line with an earlier finding reported by Perotti (2005). Output, shown in the next row, features impact (maximum) increases of 0.32 (0.46) percent in S1 and of 0.20 (0.26) percent in S2. The responses are significant in both samples, but only in S1 is the increase significant for an extended period of about two years. The response of the real wage is reported in the third row. Here a significant increase can be observed only for the first sample. Note that this seems consistent with the findings reported by other studies that cover longer sample periods. Specifically, Galí et al. (2004) also report an increase in the real wage on the basis of a VAR on US data from 1954-1998. The results for the period 1960-1996 examined by Fatás and Mihov (2001), in turn, depend on the precise wage measure under study. While most of the measures rise in response to a spending shock, only manufacturing wages do so significantly.

The fourth row depicts the response of consumption. Although the point estimates for the first few periods look rather similar, the response is significantly positive in S1 for about two years, but not so in S2. This accords qualitatively with the earlier findings of Mihov (2003) and Perotti (2005) regarding a weaker response of private consumption in S2 relative to S1. However, the most striking difference across samples consists in the much greater persistence of the effect in S1.

The last set of panels pertain to the response of government debt (measured at the end of the period) relative to GDP. Here the differences across samples are most remarkable: in S1 the debt ratio falls significantly in response to an increase in government spending, whereas in S2 a significant increase in the debt ratio can be observed. This finding seems again consistent with Perotti (2005), although he does not consider debt but tax revenues in the VAR. Specifically, Perotti notes that the cumulative net tax response to a spending shock is typically positive in S1 and negative in S2.¹³

Another way to summarize the evidence is provided by table 1, which reports the cumulated impulse responses, for 4, 12 and 20 quarters, for all variables and both samples. Most interestingly, the cumulative response of consumption (output) in the second sample is only about one third (one half) of the cumulative response in the first sample. Similar differences are also visible for government spending itself and even more for the cumulative wage response. The right column of table 1 reports the difference in the cumulative responses between both samples. For all variables and at almost all horizons, the difference exceeds one to two standard errors.

Overall, our results add corroborating evidence to the observations reported by Perotti (2005) and Mihov (2003). A comparison of both samples points towards a substantial change in the transmission of spending shocks. In particular, the responses of output and consumption are less significant and less persistent in the

¹³Note that Perotti also calculates the cumulative deficit response and finds it positive in both samples, although much larger in S2 (2.8 vs. 0.8).

second sample. Government spending itself also shows less persistence in S2. Likewise, real wages increase over an extended period in S1 but only briefly in S2. Finally, the responses of government debt indicate a change in the financing of a typical government spending shock: while in S1 an increase in government spending is associated with a fall in the debt ratio, in S2 the opposite holds, indicating more reliance upon deficit financing of spending.

3.4 Estimating the Structural Model

3.4.1 Minimum-distance strategy

The next step of our analysis consists in matching empirical (VAR) and theoretical (DSGE) impulse responses in order to obtain estimates for the parameters of our model. Rotemberg and Woodford (1997) were the first to suggest this minimum-distance technique in the context of DSGE models. Similar approaches have subsequently been applied by Amato and Laubach (2003), Boivin and Giannoni (2003) and Christiano, Eichenbaum and Evans (2005).

Generally, one important question in minimum-distance estimation concerns the issue of which moments or auxiliary statistics to match. From an econometric point of view, the moments used in estimation should be as informative as possible, in the sense of bearing strong and distinct relationships with each of the structural parameters. Unfortunately, it is often difficult to evaluate this property in a stringent way. In addition, this is not the only relevant criterion for choosing moments. Indeed, from an economic point of view, the moments should also be important in their own right. This means, in particular, that they should represent aspects of the data on which economic interest is centered, e.g. because they are clearly linked with important theories or because they matter most for economic policy. In the case of fiscal policy which we consider, a crucial issue is the response of output and its components to a shock in government spending. Moreover, since the real wage plays a central role in the transmission of fiscal shocks in our theoretical model (see Section 2.6), we also match its response.¹⁴ Both the direction and the size of these responses are important benchmarks on which to measure the descriptive quality of competing models. Accordingly, we consider, as the relevant feature to match, the empirical impulse response functions that were presented in the previous section. In doing so we concentrate on the propagation of one particular shock, whose identification is consistent with both our theoretical model and a number of prominent contributions in the empirical literature. Consequently, this strategy allows us to avoid making restrictive assumptions on the nature and interaction of all other possible shocks in the economy, as would be required, for example, in maximum likelihood estimation.

Formally, define Ψ^e to be the empirical impulse response function characterizing the data. Note that it is not a raw moment but a transformation of the estimates

¹⁴Note that, in doing so, we implicitly address a potentially important criticism having to do with the cyclicalities of real wages - see Christiano and Eichenbaum (1992).

obtained from a VAR that nests the log-linearized model. The model itself, in turn, assigns to each admissible vector of structural parameters θ a theoretical impulse response function $\Psi^t = \Psi(\theta)$. The binding function $\Psi(\cdot)$ must be assumed to be injective to ensure identification. We obtain an estimate for the parameter vector of interest, $\hat{\theta}$, by minimizing the weighted distance between empirical and theoretical impulse response functions, i.e. Ψ^e and Ψ^t :

$$\hat{\theta} = \arg \min (\Psi^e - \Psi(\theta))' W (\Psi^e - \Psi(\theta)), \quad (3.17)$$

where W represents a positive definite weighting matrix.

As the relationship between structural parameters and the implied impulse response functions is non-linear, we rely on numerical methods to obtain a solution for (3.17). Basically, $\Psi(\theta)$ is evaluated repeatedly for different parameter vectors θ , until the closest fit with the empirical impulse responses, Ψ^e , has been obtained.

Our choice of the weighting matrix W is guided by the idea of giving greater weight to impulse responses that are more precisely estimated. Thus we opt for the diagonal matrix W^{diag} whose diagonal entries are the reciprocal values of the variance of the empirical impulse responses. Using this weighting matrix ensures that the theoretical impulse responses are made to be as close to the empirical ones as possible, in terms of point-wise standard deviations. Regarding the length of the impulse response series to be considered, we decide to consider the first 20 quarters for all five variables.

Standard errors for $\hat{\theta}$ are computed using the following expression for the asymptotic variance of our estimator, taken from Wooldridge (2002):

$$\widehat{Avar}(\hat{\theta}) = (G'WG)^{-1} (G'W\hat{\Sigma}WG) (G'WG)^{-1}. \quad (3.18)$$

where $G = \nabla_{\theta} \Psi^t$ represents the Jacobian of the impulse response function generated from the model and $\hat{\Sigma}$ denotes the bootstrap-estimated variance matrix of the impulse responses.

3.4.2 Parametric setup

We partition the parameters of our structural model in three groups. The first group comprises parameters that can be fixed before the actual estimation exercise, because their values are uncontroversial or easily inferred from first moments of the data. Specifically, this is true for the time discount rate β which we set to $1.03^{-1/4}$, matching the inverse of the steady-state gross real rate of return at quarterly frequency. Further, we set the share of government expenditure in GDP, G_Y , to 0.2 and the steady-state tax rate, τ , to 0.3. Together with the assumption that the steady-state share of debt $B_{PY} = 0$, these pin down lump-sum transfers in steady state. The elasticity of substitution ε is chosen such that the markup in steady state equals 20 percent. Lastly, we also assume that, in steady state, agents spend one fourth of their time endowment working.

The remaining parameters are those that could, in principle, be estimated using our minimum-distance strategy. However, given the set of moments we exploit, certain parameters are not particularly well identified, so we find it preferable to fix them at values that have been established in the previous literature. This also helps us to keep the dimension of our optimization problem tractable. Thus we fix α , the probability that prices are not changed in a given period, at 0.77 (S1) and 0.84 (S2), corresponding to the estimates reported by Galí and Gertler (1999), who apply single-equation estimation techniques to the New Keynesian Phillips curve¹⁵. Similarly, we fix σ , which measures the inverse of the intertemporal elasticity of substitution, at a conventional value of two.

The third set of parameters comprises those that we actually seek to estimate. These are: the Taylor rule coefficient ϕ_π , the parameters governing fiscal policy, i.e. $\rho_1, \rho_2, \phi_g, \phi_b$ and η , as well as the share of non-asset holders, λ . All of these parameters are allowed to vary across the two samples. In total, we thus provide estimates for 14 parameters.

Finally, we have to take into account that certain parameter configurations could imply equilibrium indeterminacy in our theoretical model.¹⁶ In this case, we resort to the well-known minimal state variable criterion of McCallum (1999) in order to select an equilibrium and compute the corresponding impulse response functions.

3.5 Results

Table 2 provides the results of our estimation exercise for both samples. We estimate on the basis of (3.17), using the diagonal weighting matrix W^{diag} described above. Standard errors based on (3.18) are reported below the respective point estimates. Almost all parameters are estimated with satisfactory precision, although the differences between estimates for the two samples tend to remain below the usual levels of statistical significance. Before discussing the results in greater detail, note also that the set of estimates imply a determinate equilibrium for each sample, despite the fact that uniqueness was not imposed a priori.

Perhaps the most interesting single parameter, the estimated extent of asset market participation differs considerably across periods. Specifically, the share of consumers who do not smooth consumption by trading in assets is estimated at a significant $\hat{\lambda} = 0.52$ in S1 and at 0.32 in S2 (note that while the S1 value is statistically significant, the S2 value is not). This finding is consistent with the notion that access to asset markets has widened substantially over the last two decades, with potentially important consequences for the transmission of fiscal policy. In our view, the increase in asset market participation that speaks from our exercise can be related to important institutional changes occurring at the beginning of the 1980s.

¹⁵Galí and Gertler (1999) consider the samples 1960:1-1979:4 and 1980:1-1997:4.

¹⁶Indeed, our theoretical model can exhibit equilibrium indeterminacy coming from a variety of interacting sources: monetary policy, debt dynamics, the presence of non-asset holders and non-separability of utility.

Some of the suggestive evidence regarding these changes was already mentioned in the introduction; for further details see Mishkin (1991) and Bilbiie (2004). Overall, the micro evidence on financial market participation seems neatly in line with our estimation results.

With respect to monetary policy, we detect a considerable change in the way the nominal interest rate is adjusted in response to expected inflation, the parameter ϕ_π being estimated at 1.01 for S1 and 1.57 for S2. Note again in this context that our estimate of ϕ_π has not been restricted to be greater than one and that parameter configurations implying equilibrium indeterminacy have been admitted throughout. Still, our procedure turns out to deliver an estimate that actually implies a determinate and unique equilibrium. Interestingly, the estimates are even fairly close to those reported by Clarida, Galí and Gertler (2000). Using single equation techniques, these authors report an implied long-run response coefficient of 1.58 for a post-82 sample, while their corresponding estimate for data up to 1979 is 0.83. In line with the literature, our results thus suggest that the FED has adopted a stronger anti-inflationary stand under Chairmen Volcker and Greenspan compared to their predecessors in the 1960s and 1970s.

Turning to the parameters characterizing fiscal policy, note first that the estimate for ϕ_b of -0.09 in both samples implies a tendency towards debt stabilization: in response to a higher level of debt, the structural deficit is reduced in both samples. The order of magnitude of these estimates is in line with results obtained by Bohn (1998) using single equation techniques. The second important fiscal-policy parameter, ϕ_g , governs the degree of deficit finance associated with a government spending shock. Here, we observe a substantial change across samples, the estimate rising from 0.17 to 0.58 , suggesting an increase in the reliance on deficits to finance a spending unit. This result clearly reflects the strong increase in debt which, according to the empirical impulse responses, follows a sudden increase in government spending in S2 but not in S1. Next, the autoregressive parameter η is estimated to increase from 0.46 to 0.75 from S1 to S2, implying greater persistence of deficits in the second sample. These values are higher than the 0.25 reported in Galí and Perotti (2003), who use single-equation techniques and allow the deficit to respond to the output gap instead of government spending. Finally, ρ_1 is estimated to be 1.04 (S1) and 0.65 (S2), while ρ_2 is estimated to be -0.08 (S1) and 0.25 (S2). These coefficients sum up to 0.94 and 0.90 , respectively, thus reflecting the higher persistence of the spending response in S1.

Taken together, our estimation exercise provides a set of parameter values that strike us as plausible and insightful. The estimates indicate that the principal changes from S1 to S2 consist of widened private access to asset markets, more hawkish monetary policy, and a greater degree of deficit finance. The goal of the next section will be to relate these changes in institutions and policies to the differences in fiscal transmission that are visible from the empirical impulse responses in figure 1. Specifically, in a model-based counterfactual analysis we will attempt to evaluate which of the three factors - asset markets, monetary policy, or fiscal policy itself - have been pivotal for the observed decline in the effects of government

spending on the US economy. For this exercise to be meaningful, we would like our model to give a reasonably good account of the dynamic responses in the data. The low criterion function minima reported in table 2 already suggest that the theoretical impulse responses do not differ too much from the empirical ones in terms of point-wise standard deviations. Graphically, the good fit can be seen from figure 1, where we reproduce the impulse responses implied by the parameter estimates of table 2 (solid starred line). The figure clearly shows that the model accounts quite well for the VAR-based evidence on fiscal policy transmission. Both the magnitude and the persistence of the impulse responses are replicated, and the model-based responses remain consistently within the empirical confidence intervals. While in S1 fiscal policy has a strong and persistent effect on output, wages and consumption, these effects are less significant and considerably less persistent in S2. The behavior of debt in the data is also matched by the model.

3.6 Model-based counterfactual analysis

One neat implication of working with a structural model of the macroeconomy is that well-defined "policy experiments" can be considered in a way that is less prone to the Lucas critique than counterfactual simulations of reduced-form models. Specifically, keeping constant the model structure and deep parameters across samples, we are in a position to explore various possible causes for the apparent changes in the transmission of fiscal shocks. To do so, we rely on counterfactual experiments similar in spirit to the exercise provided by Boivin and Giannoni (2003) and Stock and Watson (2003) in the context of monetary policy.

Basically, we seek to assess three hypotheses for why fiscal policy may have weaker effects in S2: i) changes in the conduct of fiscal policy as reflected in the estimated parameters $\{\rho_1, \rho_2, \phi_g\}$; ii) changes in the monetary regime as reflected in the parameter ϕ_π ; iii) an increase in asset market participation, i.e. the estimated fall in λ . While these policy or institutional parameters are subject to change over time, we posit that everything else has remained stable between S1 and S2, so differences in transmission are necessarily caused by some combination of changes in the above-mentioned parameters.

The goal of this section is to evaluate which parameter changes, in particular, may be critical for obtaining the reduced effects of government expenditure. Needless to say, the full extent of variation between S1 and S2 can only be accounted for by simultaneous variation of all estimated parameters. Put differently, there are possibly important interactions between different parameters, so the observed changes between S1 and S2 are not simply the sum of the effects of univariate parameter changes. Although we cannot investigate all of the possible cross effects, we still deem it worthwhile to investigate which individual parameter change alone would seem most powerful in driving our results.

In our subsequent analysis, we therefore vary one parameter at a time from its estimated S1 value and evaluate the impact on the model's dynamic implications

relative to the fitted S1 impulse responses. Figure 2 contains all the results. To illustrate what is to be accounted for, i.e. the change in transmission according to our estimates, the first column displays the theoretical impulse responses of all five variables based on the respective parameter estimates for S1 and S2. As stated before, all variables display a much less persistent response in S2, while the response of the debt ratio even changes sign.

The panels in column b) display the responses corresponding to the S1 parameter estimates along with the first set of *counterfactual responses*. The latter result from an evaluation of the model based on all parameters taking their S1 values except λ , which is reduced from 0.52 to its S2 value of 0.32. This experiment is meant to gauge the effect of a counterfactual increase in asset market participation from 48 to 68 percent in the early sample. As a result, the responses can be seen to exhibit less persistence, because greater asset market participation allows more households to internalize the government budget constraint, so private consumption is reduced relative to the S1 baseline case. Note that the quantitative magnitude of this may be understated due to our use of the point estimate of λ for S2 in the counterfactual exercise. Indeed, taking into account that this estimate is in fact insignificant would reinforce this effect and lead to yet weaker responses of output, consumption and real wages. To the extent that the consumption and output responses are muted, the increase in asset market participation works towards explaining the smaller effect of government spending.

However, this effect has to be put into perspective by considering our next experiment. The panels in column c) display the consequences of varying the degree of monetary policy activism, i.e. the effect of increasing ϕ_π from 1.01 to 1.57. Indeed, the observed change in responses is more dramatic in this case, notably for consumption. We interpret this piece of evidence as follows: Had monetary policy been more anti-inflationary in S1, a typical increase in government spending, by inducing inflation, would have triggered higher nominal interest rates and caused households to postpone consumption. This would have dampened consumption, output and the real wage enough to drive their responses close to or even below the levels observed for S2. It is in this sense that the estimated change in monetary policy turns out to be a quantitatively powerful factor pushing results in the right direction, i.e. a smaller expansionary impact of government spending shocks on the economy after 1980. As can be seen from the second last row of column c), consumption would have actually fallen on impact, if only monetary policy had changed from its S1 to its S2 stance. Moreover, a more active monetary policy would have induced a mild increase in the debt to GDP ratio as the tax revenues would have been lower relative to the S1 baseline case. However, note that this experiment leaves the *shape* of the impulse responses largely unaffected. Therefore, while the change in monetary policy plays a large role in explaining the change in the *magnitude* of the responses at a given point in time, it cannot, by itself, account for the change in the *dynamic pattern* (and notably persistence) of the responses to a government spending shock.

The last two columns consider changes in the conduct of fiscal policy itself. First, in column d) we compare the fitted S1 responses with what would have happened

if the process of government expenditure had been less persistent. Specifically, we change both ρ_1 and ρ_2 to their respective S2 values, while all other parameters stay at their S1 levels. Lower persistence in government spending implies a weaker negative wealth effect and therefore might, on the one hand, reduce the negative effect of a spending shock on private consumption. On the other hand, lower persistence also induces a smaller increase in labor demand and hence the real wage, which, in turn, strengthens the negative effect on private consumption. As our results show, the second effect appears to dominate in this case. Output increases less than under the S1 baseline scenario if the lower persistence of the S2 spending process is assumed. As a result, the consumption response turns out weaker, as well. Although these effects do go in the right direction, they seem relatively limited, especially compared to the contribution of monetary policy examined before.

Finally we evaluate the consequences of altering the degree of deficit finance. For this purpose, we set the relevant parameter ϕ_g from its S1 value of 0.17 to the higher S2 value of 0.58. The panels in column e) show that such a change would induce much stronger positive responses of all variables and prevent a fall in debt. While the more pronounced increase in consumption, output and the real wage runs counter to the observed differences between S1 and S2, the stabilization of debt actually works towards accounting for the rise in debt observed in the second sample. Apparently the rise in ϕ_g is crucial for the change of sign in the debt response, while its counterfactual implications for the remaining series are offset by other simultaneous parameter changes.

Overall, our exercises suggest the following tentative conclusion. The change in the effects of government spending identified in the empirical exercise regards both the *magnitude* and the *dynamic pattern* of the impulse responses. Among the individual parameter changes that we consider, a more active monetary policy appears to be the most powerful factor driving down the *magnitude* of the effects of government spending on consumption and output in the second sample. The dampening effect of a tougher anti-inflationary stance is complemented by greater asset market participation and less persistent spending shocks, although the latter two changes affect the magnitude in a quantitatively less important way. However, in order to account for the change in the *shape and persistence* of the responses, the increase in asset market participation in particular and changes in parameters governing fiscal policy are necessary. Hence, while none of the candidate explanations can by itself provide a satisfactory account of the change in the effects of government spending, our counterfactual experiments identify the specific role played by each of these explanations.

3.7 Conclusion

In this paper, we make essentially two contributions. First, we add to the emerging evidence that the transmission of government spending shocks in the US economy has changed substantially in the post-1980s. Second, we try to account for these

changes by considering a DSGE model whose implications for fiscal transmission are driven by a set of structural and institutional parameters.

To establish the stylized facts of fiscal transmission, we consider a parsimonious VAR that is specified in accordance with our theoretical model. The main finding is that an exogenous increase in government spending leads to a sustained rise in output, consumption and the real wage in the period 1957-1979 but has less significant and much less persistent effects on these variables after 1982. Moreover, the financing of government spending shocks appears to have changed, as indicated by the distinct responses of government debt across the two samples. Together, these results confirm earlier studies by Perotti (2005) and Mihov (2003).

Why does US fiscal policy have less expansionary effects in the second sample? Starting from our VAR-based evidence, we try to relate the differences in fiscal transmission to important institutional and policy changes in the US economy. Clearly, our analysis must confront the Lucas critique, so we resort to a structural model. Specifically, we propose a New Keynesian DSGE model that features limited asset market participation as a potential institutional explanation for different degrees of fiscal policy effectiveness. In addition, the model encompasses simple specifications of both fiscal and monetary policies, so several competing hypotheses can be taken into account as to the reasons for the observed change in fiscal transmission.

We take our structural model to the data by matching its implied impulse responses with those obtained from the VAR. In contrast to many other applications of minimum distance estimation, we ensure that the model's dynamics are fully nested in the VAR, thus addressing a recent critique of Chari, Kehoe and McGrattan (2005). Our approach provides us with estimates of the key policy and institutional parameters for the early and the late sample, respectively, while all deep parameters are held constant. The results suggest that asset market participation increased noticeably in the post 1980s, in line with earlier informal evidence. We also find that government spending has become less persistent but more deficit-financed in the second sample and that monetary policy has become more active.

Given these estimates, we carry out counterfactual experiments within the framework of our structural model. Specifically, we consider the quantitative impact of single policy or institutional reforms in order to evaluate which of the candidate changes in the US economic environment is most powerful in accounting for the differences in fiscal transmission before and after 1980. A *ceteris paribus* increase in asset market participation to the level estimated for the second sample leads to somewhat weaker output, consumption and real wage effects of a government spending shock, thus explaining part of the difference in the fiscal multiplier across samples. Importantly, and unlike changes in any other parameters, it also leads to a change in the *shape* of the impulse responses consistent with that observed in the data. The most important single determinant of the change in the *magnitude* of the effects, however, turns out to be the observed change in monetary policy as a tougher anti-inflationary stance after 1980 has acted to reduce the expansionary effects of a surprise increase in government spending. Finally, changes in fiscal policy parameters (persistence of shocks and, more importantly degree of deficit financing)

play a somewhat more limited role in accounting for the difference in the responses of output, consumption and wages, but the latter is crucial in explaining the dynamics of debt. In our view, these results highlight the importance of considering the interaction of monetary and fiscal policy on the one hand, and macro policies and the development of financial markets on the other, to gain a better understanding of how important shocks are transmitted in the macroeconomy.

3.8 Appendix

A. Steady state

Here we calculate the coefficients used in the log-linearized equilibrium. For any variable X_t , X denotes its steady-state value and X_Y its steady-state share in output, X/Y . The Euler equation (3.3) implies $1 + r \equiv R = 1/\beta$. From the firm's problem (3.12), we have for the real wage

$$\frac{W}{P} = \frac{\varepsilon - 1}{\varepsilon}, \quad (3.19)$$

while production (3.11) in steady state implies $Y = N - F$. Defining $\mu = \frac{\varepsilon}{\varepsilon - 1} - 1$, we rewrite (3.19) as

$$\frac{W}{P} = \frac{Y + F}{N(1 + \mu)} = \frac{Y}{N} \frac{1 + F_Y}{1 + \mu}.$$

Profits in steady state imply $O = Y - [W/P]N$, so that profits over output are given by

$$O_Y = \frac{\mu - F_Y}{1 + \mu}.$$

We assume that hours are the same for the two groups in steady state only, $N_N = N_A = N$. Because of preference homogeneity (see section 2), we need to ensure that steady-state consumption shares are also equal across groups. This can be seen by comparing (3.5) with (3.8) evaluated at the steady state:

$$\frac{C_A}{L} = \frac{1 - \tau}{\varphi} \frac{W}{P} = \frac{C_N}{L}$$

implying $C_A = C_N = C$. The steady-state coefficients needed for our log-linear approximation below are fully determined as:

$$\begin{aligned} (1 - \tau) \frac{W}{P} \frac{N}{Y} &= (1 - \tau) \frac{1 + F_Y}{1 + \mu}; \\ \frac{C_A}{Y} &= (1 - \tau) \frac{1}{1 - \lambda} \left(1 - \lambda \frac{1 + F_Y}{1 + \mu} \right) - T_Y; \\ \frac{C_N}{Y} &= (1 - \tau) \frac{1 + F_Y}{1 + \mu} - T_Y; \\ T_Y &= G_Y - \tau. \end{aligned} \quad (3.20)$$

We achieve equalization of steady-state consumption shares (as required by preference homogeneity coupled with equalization of hours) by making assumptions on technology. Specifically, we ensure that asset income in steady state is zero. This is achieved by assuming that the fixed cost of production is given by: $F_Y = \mu$.¹⁷ Substituting into (3.20) gives:

$$\frac{C_A}{Y} = \frac{C_N}{Y} = C_Y = 1 - \tau - T_Y = 1 - G_Y.$$

Next, we want to find hours in steady state. Solving the intratemporal condition after imposing equalization of hours and consumption we have (normalize $P = 1$):

$$\frac{C}{1-N} = \frac{1-\tau}{\varphi} W \rightarrow (1-\tau) W N - T = \frac{1-\tau}{\varphi} W (1-N).$$

Dividing by Y and using (3.20) and the expression for the fixed cost we obtain constant steady-state hours given by:

$$\frac{N}{1-N} = \frac{1}{\varphi} \frac{1-\tau}{1-G_Y}. \quad (3.21)$$

Given τ and G_Y , we choose steady-state N to match average hours worked, which implies from (3.21) an unique value for φ .

B. Log-linearized equilibrium

A local approximation of the model outlined in section 2 around its non-stochastic steady state delivers a dynamic system of linear difference equations that can be solved numerically. We outline the log-linear equations in this appendix. Small letters denote the log-deviation of a variable from its steady-state value while $\hat{b}_t = B_t / (P_{t-1} Y_{t-1})$, $\pi_t = \log(P_t / P_{t-1})$ and $w_t = \log((W_t / P_t) / (W / P))$. The sequences for the set of variables we consider satisfy the following 13 conditions/definitions. Linearizing the Euler equation (3.3) and substituting steady-state hours from (3.21) gives

$$\begin{aligned} c_{A,t} = & E_t c_{A,t+1} - \frac{1}{\sigma} (\tau_t - E_t \pi_{t+1}) \\ & + \left(1 + \frac{T_Y}{1-G_Y} \right) \left(\frac{1}{\sigma} - 1 \right) (E_t n_{A,t+1} - n_{A,t}). \end{aligned}$$

Note that when $\sigma > 1$, the elasticity of consumption growth ($E_t c_{A,t+1} - c_{A,t}$) to hours growth ($E_t n_{A,t+1} - n_{A,t}$) becomes positive. In addition, the elasticity of consumption to real interest rates is given by $1/\sigma$. The labor choice of asset holders (3.5), in log-deviations from steady state, is given by

$$\frac{N}{1-N} n_{A,t} = w_t - (c_{A,t} - \gamma c_{t-1}).$$

¹⁷Note that this assumption implies that the share of profits in steady state, D_Y , is zero, in line with the evidence and arguments in e.g. Rotemberg and Woodford (1995).

The linearized first-order condition and budget constraint, (3.8) and (3.7), for non-asset holders read as follows:¹⁸

$$\begin{aligned}\frac{N}{1-N}n_{N,t} &= w_t - (c_{N,t} - \gamma c_{t-1}), \\ (1 - G_Y)c_{N,t} &= (1 - \tau)(w_t + n_{N,t}) - T_Y t_t.\end{aligned}$$

Labour market clearing, using $N_A = N_N = N$, implies

$$n_t = \lambda n_{N,t} + (1 - \lambda)n_{A,t},$$

Aggregate consumption is given by

$$c_t = \lambda c_{N,t} + (1 - \lambda)c_{A,t},$$

Up to a first-order approximation, the aggregate production function (3.11) is given by

$$y_t = (1 + F_Y)n_t,$$

A log-linear approximation of the price setting problem (3.12), together with the definition of the price level, implies

$$\pi_t = \beta E_t \pi_{t+1} + \frac{(1 - \alpha)(1 - \alpha\beta)}{\alpha} w_t.$$

Next, consider the government sector. An approximation to the government budget constraint (3.14) divided by output reads as:

$$\beta \hat{b}_{t+1} = \hat{b}_t + G_Y g_t - T_Y t_t - \tau y_t.$$

In turn, an approximation to the definition of structural primary deficit divided by output $\hat{d}_{s,t}$ is given by:

$$\hat{d}_{s,t} = G_Y g_t - T_Y t_t.$$

Our specification of the deficit rule (3.16) reads as

$$\hat{d}_{s,t} = \eta \hat{d}_{s,t-1} + \phi_g G_Y g_t + \phi_b \hat{b}_t.$$

Next, the monetary policy rule (3.13), in log deviations, is given by

$$r_t = \phi_\pi E_t \pi_{t+1}.$$

Finally, good market clearing implies

$$y_t = G_Y g_t + (1 - G_Y)c_t.$$

¹⁸ From these two equations, one obtains a reduced-form labor supply for non-asset holders. We have

$$n_{N,t} = \frac{\varphi}{1 + \varphi} \frac{-T_Y}{1 - G_Y + T_Y} (w_t - t_t).$$

Since $-T_Y > 0$, hours of non-asset holders respond positively to increases in the real wage w_t and taxes relative to their steady-state value $T_Y t_t$.

C. A model with money

The purpose of this appendix is to show that the principal implications of our model remain unaffected if we allow for money holdings by both agents and adopt a particular scheme for rebating seigniorage revenues. This setup gives non-asset holders some room for smoothing consumption by holding money. Suppose that utility is separable in money balances, such that period utility is, for an agent $j \in \{A, N\}$,

$$U\left(C_{j,t}, L_{j,t}, \frac{M_{j,t}}{P_t}\right) = \frac{(C_{j,t} L_{j,t}^\varphi)^{1-\sigma}}{1-\sigma} + h\left(\frac{M_{j,t}}{P_t}\right), h' > 0, h'' < 0$$

while the budget constraints become, respectively:

$$\begin{aligned} & R_t^{-1} B_{A,t+1} + P_t C_{A,t} + P_t T_t + M_{A,t} \\ &= B_{A,t} + M_{A,t-1} + (1-\tau)(W_t N_{A,t} + P_t D_{A,t}) + P_t S_{A,t}, \\ & P_t C_{N,t} + P_t T_t + M_{N,t} \\ &= M_{N,t-1} + (1-\tau)W_t N_{N,t} + P_t S_{N,t} \end{aligned}$$

where $M_{j,t}$ are end-of-period money holdings and $P_t S_{j,t}$ are nominal transfers received from the government due to seigniorage revenues. Because of utility being separable in money, the first-order conditions outlined in the main body of the paper do not change. However, there are two additional first-order conditions governing the choice of money holdings $M_{j,t}$. For each agent, $h'\left(\frac{M_{j,t}}{P_t}\right) - U_C(C_{j,t}, L_{j,t}) + \beta E_t \frac{P_t}{P_{t+1}} U_C(C_{j,t+1}, L_{j,t+1}) = 0$, which after some manipulation leads to a money demand equation:

$$h'\left(\frac{M_{j,t}}{P_t}\right) = [1 - \beta E_t \Lambda_{t,t+1}^j] U_C(C_{j,t}, L_{j,t}).$$

Since $R_t^{-1} = \beta E_t [\Lambda_{t,t+1}^A]$, we obtain a standard money demand schedule for asset holders: $h'\left(\frac{M_{A,t}}{P_t}\right) = [1 - R_t^{-1}] U_C(C_{A,t}, L_{A,t})$. Note that this money demand depends negatively on interest rates.

Importantly, non-asset holders' money demand does not depend directly on interest rates. Although $\Lambda_{t,t+1}^N$ is defined similarly to $\Lambda_{t,t+1}^A$, in contrast to the latter it does not constitute a pricing kernel. The money demand of non-asset holders merely specifies the path of money holdings as a function of the entire path of consumption and inflation (and leisure in the non-separable case):

$$h'\left(\frac{M_{N,t}}{P_t}\right) = U_C(C_{N,t}, L_{N,t}) - \beta E_t \frac{P_t}{P_{t+1}} U_C(C_{N,t+1}, L_{N,t+1}). \quad (3.22)$$

Note that money holdings will increase if present consumption increases and will fall if either future expected consumption or expected inflation increase. This introduces a channel for non-asset holders to smooth consumption that is absent in the cashless model.

In order to complete our description of the equilibrium we need to specify four more conditions (we have introduced six extra variables: $M_{A,t}$, $M_{N,t}$, M_t , $S_{A,t}$, $S_{N,t}$, S_t and two extra equations governing money demand for each agent). The first two are straightforward. Money market clearing requires: $M_t = \lambda M_{N,t} + (1 - \lambda) M_{A,t}$, while the definition of total transfers reads as $S_t = \lambda S_{N,t} + (1 - \lambda) S_{A,t}$, which will enter the government budget constraint in a straightforward way.

The last two conditions are slightly more complicated and are related to the government's policy in redistributing seigniorage revenues to each group in the form of transfers. We choose to specify this policy in a way that implies the smallest deviation of this model from both (i) a model without money and with non-asset holders as presented in section 2; and (ii) a model with money in which all agents have access to complete asset markets. Specifically, we assume that each agent j receives back in transfers precisely the amount that has been obtained from him as seigniorage:

$$S_{j,t} = \frac{M_{j,t} - M_{j,t-1}}{P_t}. \quad (3.23)$$

Note that this is effectively the same assumption as is made in standard monetary models, where everybody holds assets and agents are identical so that the same equality also holds at an aggregate level. In our framework under this assumption, however, money holdings are different across agents, which implies that transfers across agents will also be different. The redistribution scheme in (3.23) implies that the budget constraint of the non-asset holders is identical to the one before: $P_t C_{N,t} + P_t T_t = (1 - \tau) W_t N_{N,t}$, whereby consumption tracks disposable income. In fact, all equilibrium conditions of the cashless model are unaffected. The money holdings of asset holders are determined by their money demand equation for a given path of consumption, leisure and nominal interest rates, while the money holdings of non-asset holders are determined endogenously by their money demand equation for a given path of consumption, leisure and expected inflation.¹⁹

¹⁹The same would hold if the government followed a money supply rule instead of a Taylor rule. For a given growth rate of total money M_t chosen by the government, the interest rate would be pinned down by the money demand equation of asset holders.

Table 1: Cumulative Impulse Responses to Spending Shock^a

Variable	Horizon	S1	S2	S2-S1
spending	4	3.82 (0.45)	2.67 (0.32)	-1.14 (0.56)
	12	10.99 (2.57)	6.40 (1.37)	-4.58 (2.92)
	20	14.32 (4.62)	7.47 (2.58)	-6.84 (5.26)
output	4	1.71 (0.56)	0.94 (0.43)	-0.77 (0.70)
	12	4.50 (1.48)	2.38 (1.39)	-2.12 (2.00)
	20	5.99 (2.19)	2.62 (1.91)	-3.37 (2.90)
real wage	4	0.46 (0.25)	0.50 (0.62)	0.05 (0.66)
	12	2.16 (0.81)	0.34 (1.60)	-1.82 (1.78)
	20	4.06 (1.39)	-0.89 (2.49)	-4.95 (2.85)
consumption	4	0.78 (0.41)	0.70 (0.37)	-0.08 (0.54)
	12	2.74 (1.11)	1.64 (1.39)	-1.10 (1.74)
	20	4.32 (1.65)	1.23 (2.22)	-3.09 (2.74)
debt	4	-0.26 (0.28)	0.94 (0.53)	1.20 (0.60)
	12	-1.64 (1.12)	4.92 (2.96)	6.56 (3.13)
	20	-3.55 (2.13)	8.86 (5.82)	12.41 (6.13)

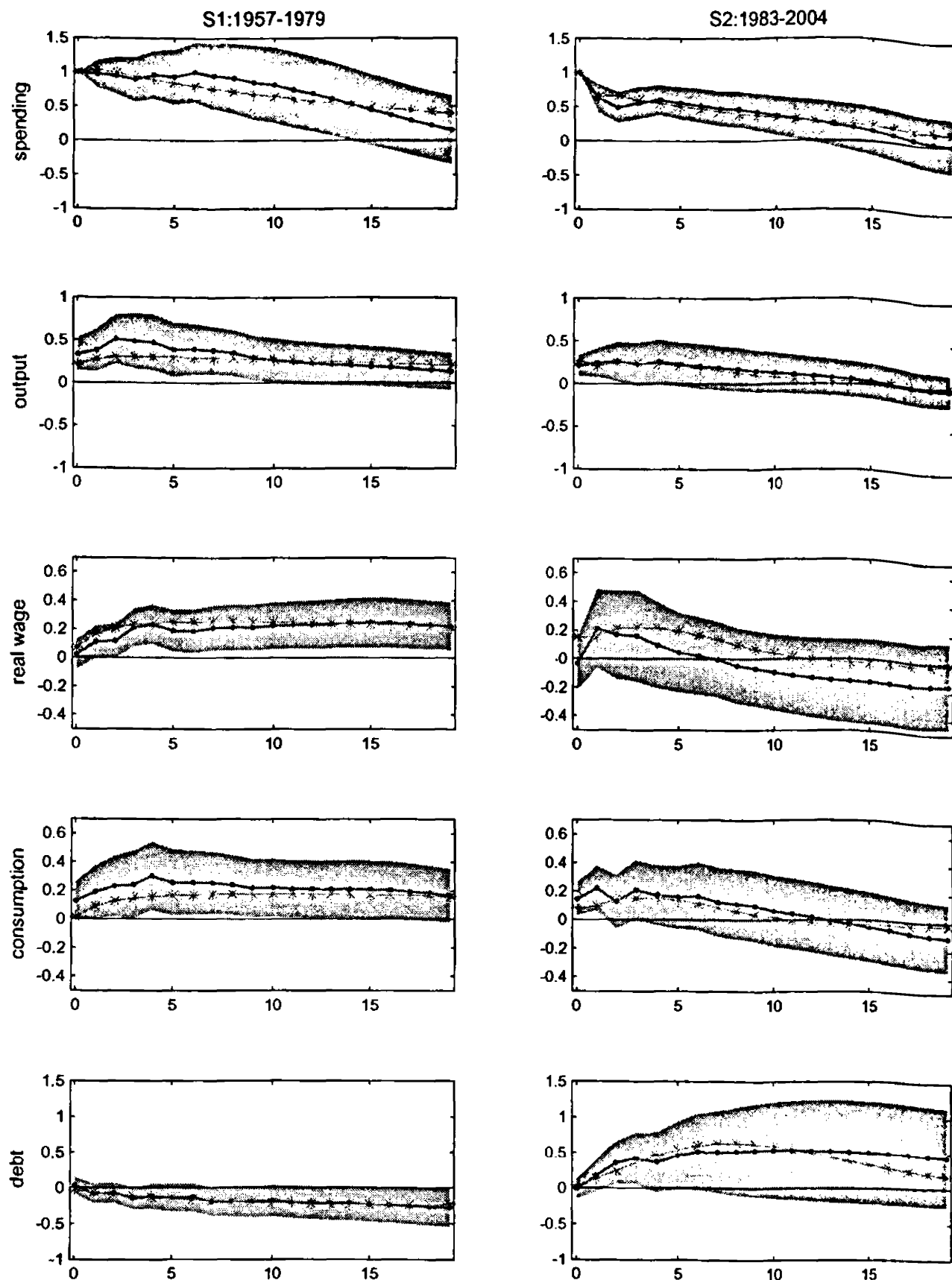
^a Responses are percent deviations from unshocked path, except for debt, which is percentage points of output. Standard errors obtained by bootstrap are reported in parentheses.

Table 2: Estimated Model Parameters^b

Parameter	S1	S2
λ	0.523 (0.065)	0.328 (0.250)
ϕ_π	1.006 (0.009)	1.573 (0.600)
ϕ_b	-0.092 (0.211)	-0.096 (0.031)
ϕ_g	0.168 (0.107)	0.580 (0.199)
η	0.457 (0.631)	0.751 (0.245)
ρ_1	1.036 (0.158)	0.649 (0.143)
ρ_2	-0.083 (0.155)	0.251 (0.144)
Loss :	23.628	26.040

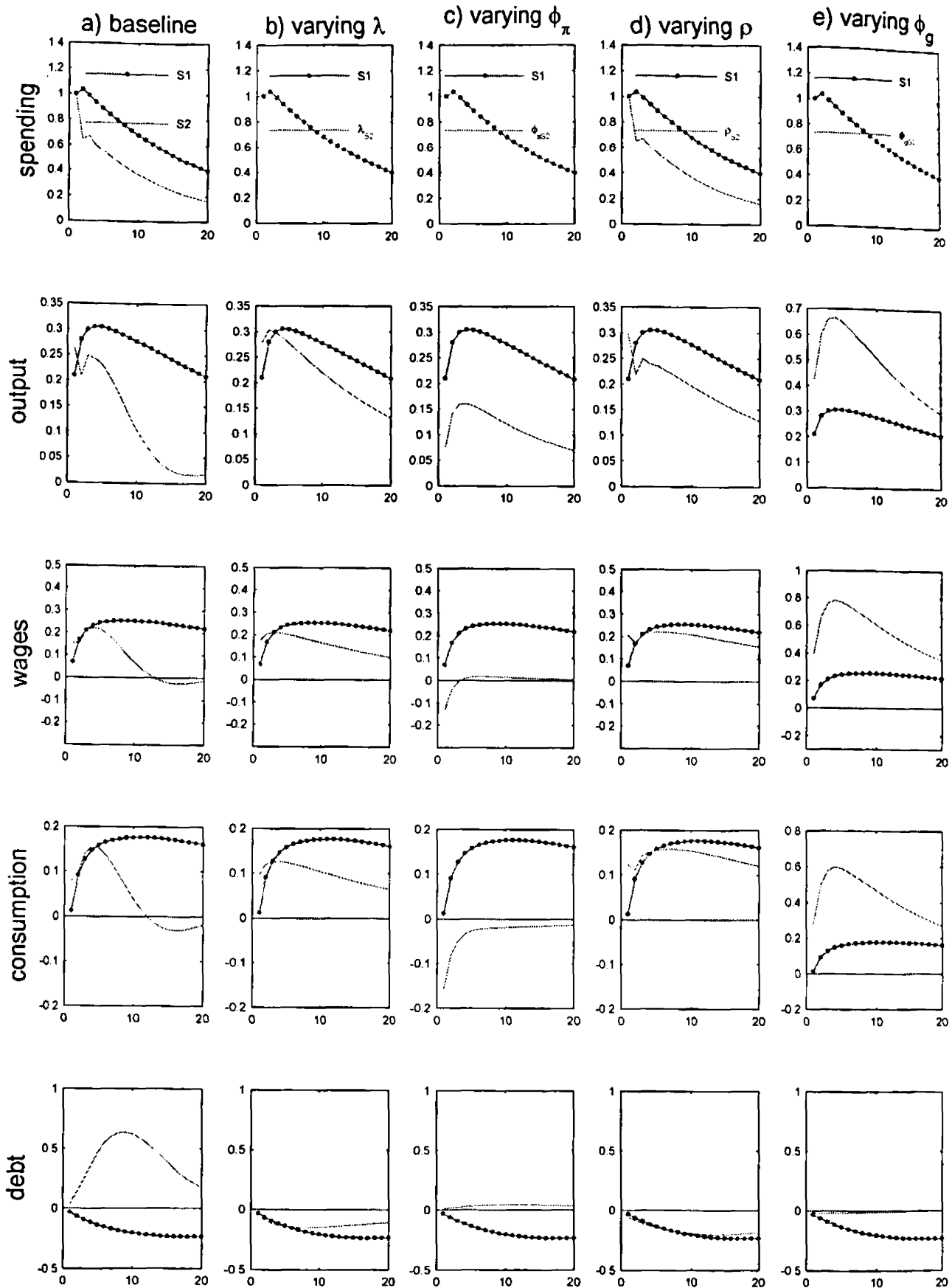
^bStandard errors are reported in parentheses.

Figure 1: Transmission in estimated VAR and DSGE model



Legend: impulse responses to one percent increase in real government spending. Shaded areas indicate bootstrapped 90 percent confidence intervals. VAR model: dots. DSGE model: stars. Vertical axes indicate deviations from unshocked path. Horizontal axes indicate quarters. DSGE model simulation based on parameter estimates obtained by matching VAR-responses.

Figure 2: What accounts for the change in transmission?



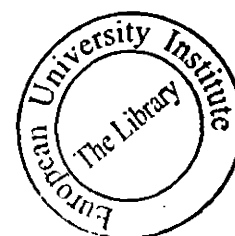
Legend: model impulse responses for S1 and S2 parameter estimates (column a). Columns b) to e) contrast responses resulting from S1 baseline estimate with counterfactual responses resulting from varying each parameter of interest from S1 to S2 estimate.

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